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GEOPHYSICS

A Journal of General and Applied Geophysics

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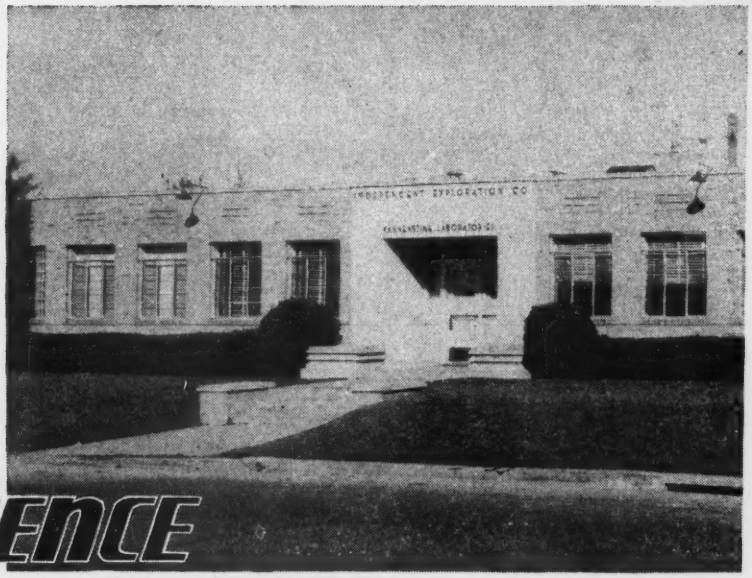

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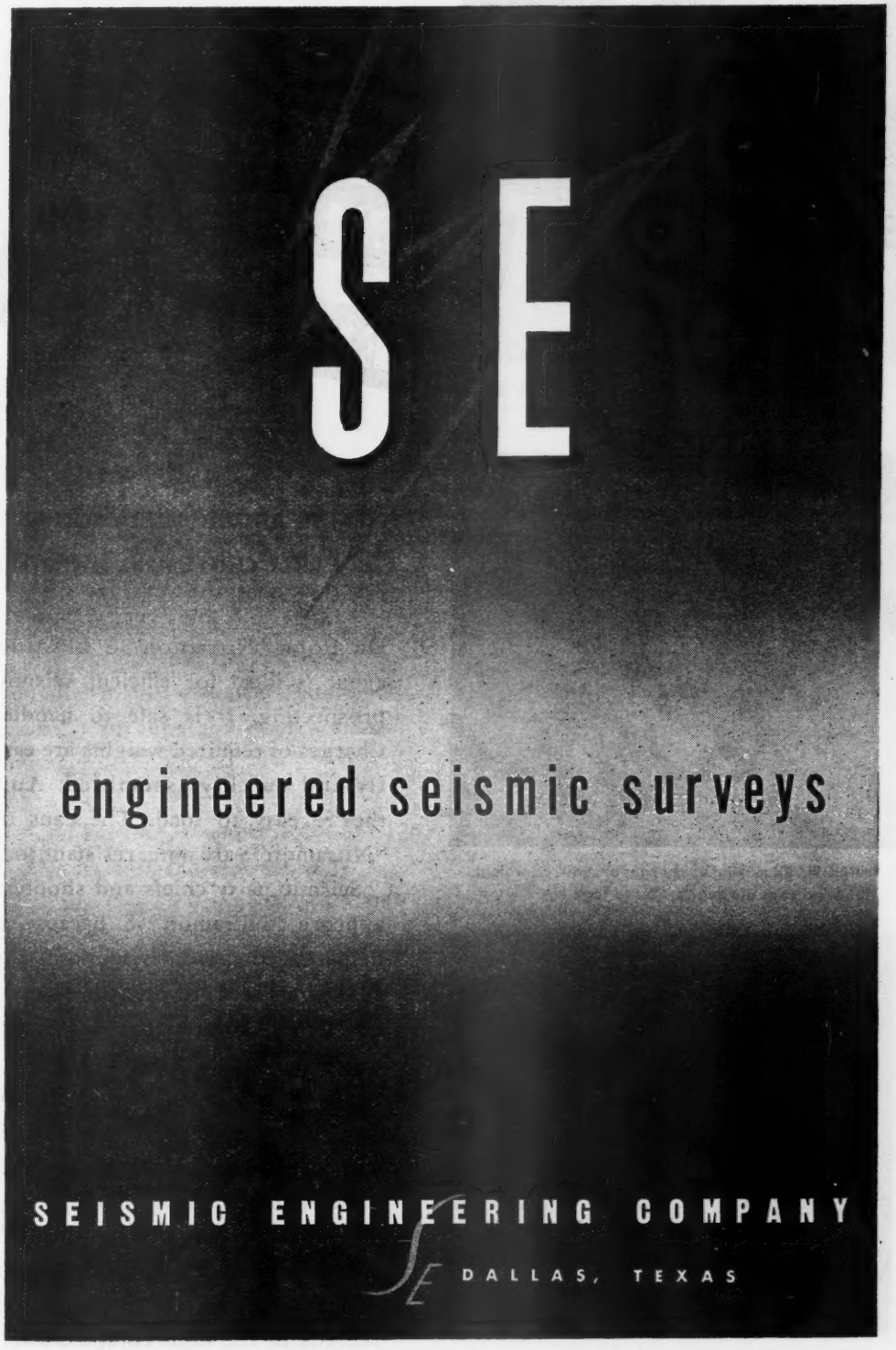
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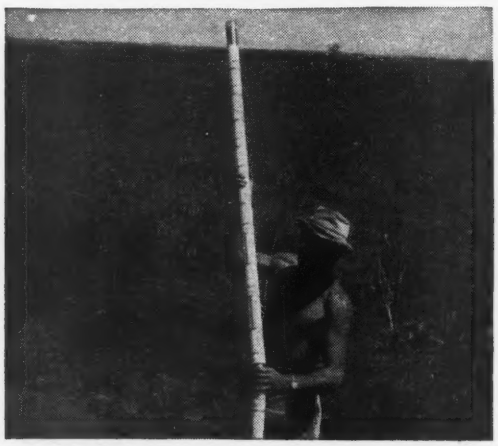

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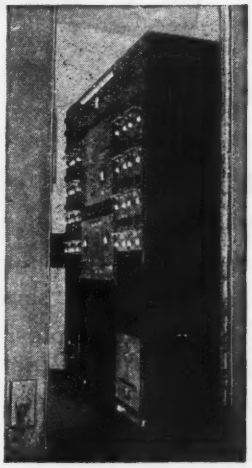

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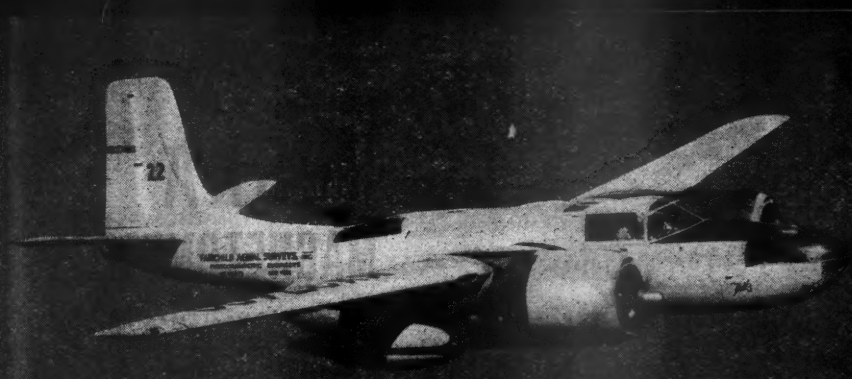

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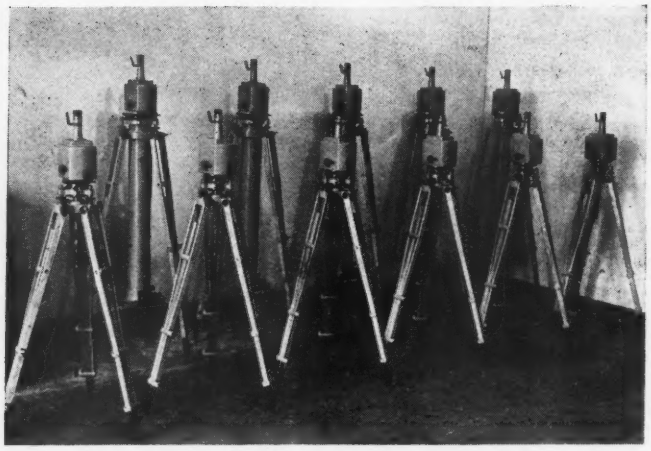

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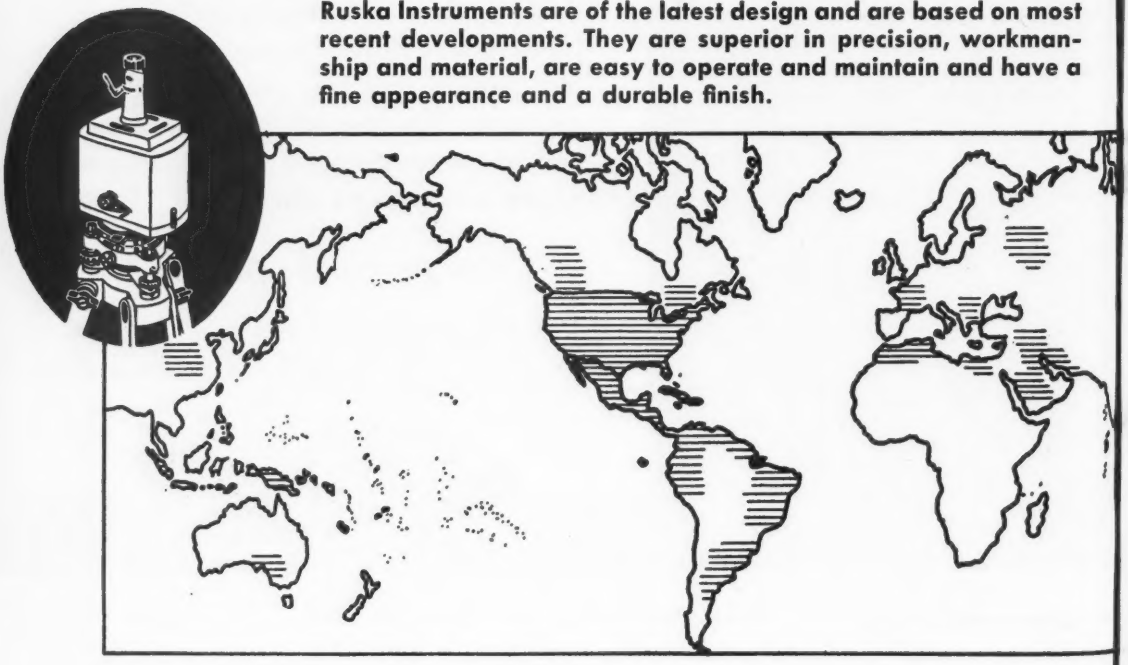

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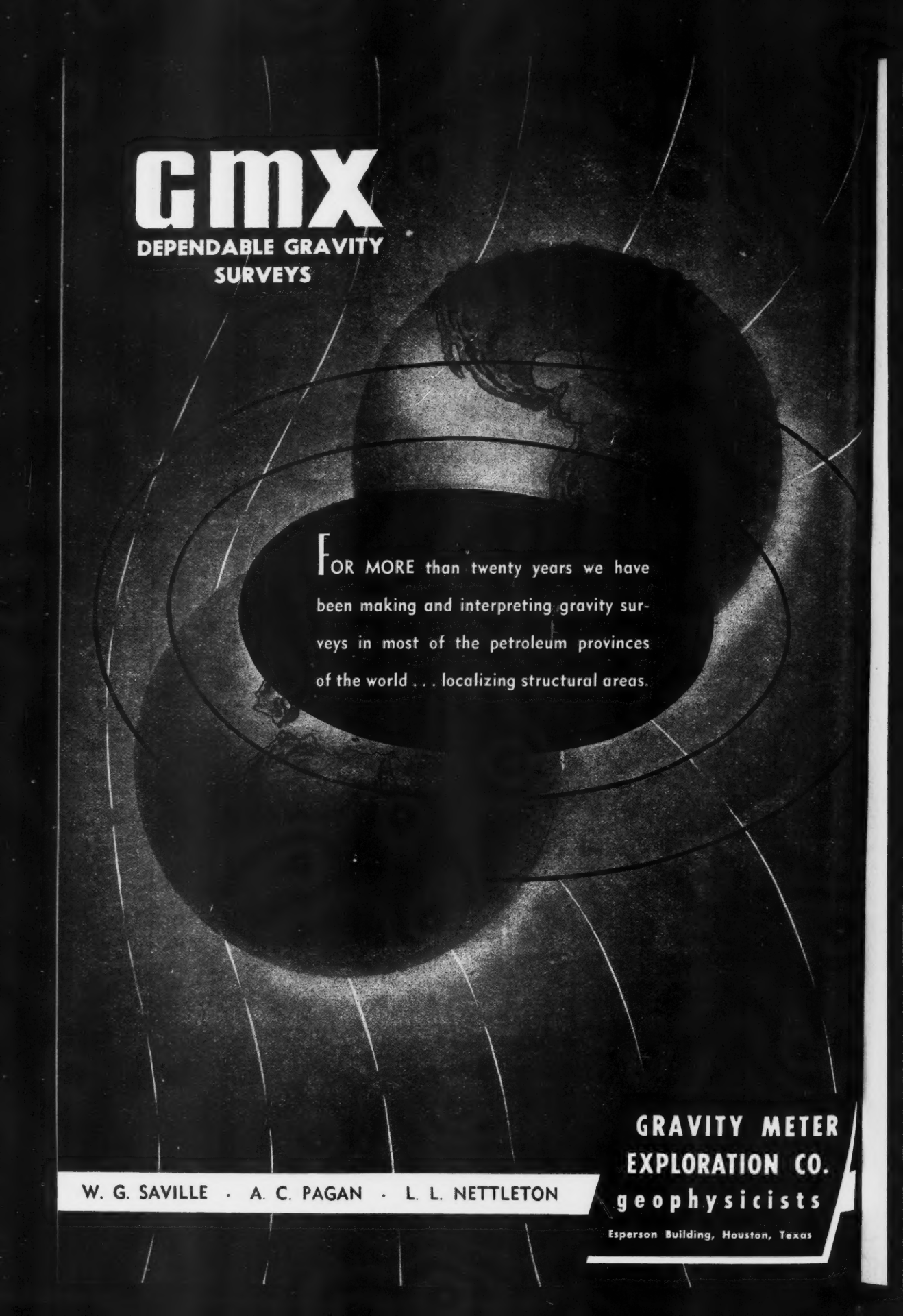
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GEOPHYSICS

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THE FUNDAMENTAL EQUATIONS OF ELECTRICAL PROSPECTING*

RAYMOND MAILLET†

In the United States the applications of electrical prospecting have been few. Thus it might appear superfluous to discuss exhaustively the method. On the other hand it has been applied quite extensively and successfully in the Eastern Hemisphere, particularly by French geophysicists, under the leadership of Conrad and Marcel Schlumberger. Important theoretical studies have resulted from this use which it is deemed worthwhile to summarize, at least along general lines.

To be brief, the author will limit himself to an outline of the essential results, leaving aside detailed mathematical developments. The latter, if advisable at all, will appear in the form of appended notes. Also, he will limit himself strictly to the use of direct current, which, alone, allows deep investigation, particularly in the case of very conductive sediments, a very common feature of oil bearing territories.

Finally, unless otherwise expressly indicated, we shall deal with horizontal strata only. Obviously the results obtained will remain still practically valid in the case of semi-horizontal formations.

In the present paper we shall recall the fundamental equations constituting the basis of electrical prospecting, and establish a relation between: (1) The law of repartition of conductivities in terms of the geological level, law represented by the electrical logging curve, on the one hand; and (2) The law of variation of apparent resistivity in terms of the dimension of the surface measuring device, law characterized by the electrical sounding diagram, on the other. We shall be led to

* Manuscript received by the Editor April 18, 1947.

† Technical counsel, Compagnie Generale de Geophysique, Paris, France.

The translation from the French is by Eugene G. Leonardon, Houston, Texas.

consider a third type of diagram, the so-called "Dar Zarrouk curve"; and finally, we shall have to recall the phenomena of anisotropy, equivalence and suppression.

1. MICRO-ANISOTROPY

Many formations, and in particular the sediments made up of clays and marls, conduct the current more easily along the strata than perpendicularly thereto. Instead of a single conductivity σ, two distinct conductivities must be considered:

(a) The longitudinal conductivity σ_l parallel to the strata;

(b) The transversal conductivity σ_t perpendicular thereto.

It is convenient to replace these two parameters by two others, namely:

(1) The average conductivity:

$$\sigma = \sqrt{\sigma_l \sigma_t}, \tag{1.1}$$

(2) The micro-anisotropy:

$$\theta = \sqrt{\sigma_l / \sigma_t} > 1. \tag{1.2}$$

Inversely, we have:

$$\sigma_l = \theta\sigma, \tag{1.3}$$

$$\sigma_t = \sigma/\theta. \tag{1.4}$$

Micro-anisotropic phenomena are, by no means, a mere scientific curiosity. At Pechelbronn (Alsace), for instance, there are marls for which $\theta = 2$. In the Russian Sarmatian, a value as high as $\theta = 3$ has been observed.

In mathematical physics, the micro-anisotropy amounts to replacing the scalar quantity σ by a tensorial density σ^{ik}.

2. FUNDAMENTAL THEORY OF MICRO-ANISOTROPY

It can be established that a layer of a thickness h and average conductivity σ and anisotropy θ is exactly equivalent, in its outside effects, to an isotropic layer of a thickness θh and conductivity σ (Fig. 1).

Inside the anisotropic layer the transverse electrical field and the longitudinal density of the current are both θ-times greater than inside the equivalent isotropic layer.

This equivalence phenomenon just described is of great moment in electrical prospecting. It is clear that no surface measurements will enable discrimination between an underground layer with an anisot-

ropy θ and an equivalent isotropic layer θ-times thicker; hence there exists a source of indeterminateness with respect to the computation of depth, which only a knowledge of the anisotropy factor will make it possible to circumvent.

The principle of equivalence, as enunciated for a plane stratum, is only a very particular case of a more general principle,[1] the derivation of which is easy with the symbols of tensor calculus (cf. Appendix 1).

This theorem has numerous applications in electrical prospecting. It can be generalized, with some reservations and only in certain cases, to the magnetic field.

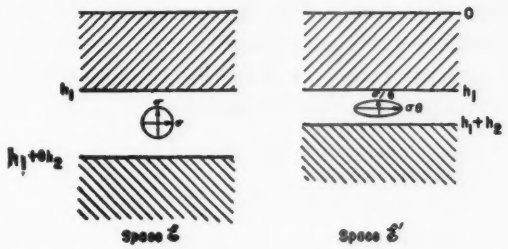

FIG. 1. Example of two spaces anisotropically equivalent.

3. MACRO-ANISOTROPY

Besides micro-anisotropy, which is, so to speak, an intimate property of the rocks, one has to consider, in geophysical prospecting, their macro-anisotropy which results from the repeated recurrence of two different facies made up of quite thin beds, an occurrence which is found, among others, in the Flysch. It is axiomatic that the current will flow more readily in the direction of the strata, utilizing mostly the conductive beds, rather than perpendicularly thereto. Hence, the action of macro-anisotropy will be similar to that of micro-anisotropy, at least if the measuring devices are geometrically large with respect to the thickness of the individual beds. This point has been rigorously demonstrated.[2]

[1] Raymond Maillet and Henri Georges Doll, *Sur un theoreme relatif aux milieux electriquement anisotropes et ses applications a la prospection electrique en courant continu*, Ergänzungs-Hefte für angewandte Geophysik, III, 1, 109–124, Akademische Verlag. (Leipzig, 1932.)

[2] C. and M. Schlumberger and E. G. Leonardon, *Some Observations Concerning Electrical Measurements in Anisotropic Media, and Their Interpretation*, American Institute of Mining & Metallurgical Engineers Tech. Publn. No. 505 (Class L, No. 40), (1933).

Let h_1 and h_2 be the thicknesses, σ_1 and σ_2 the conductivities of two individual strata. It is possible to consider an *average longitudinal conductivity* σ_l and an *average transversal conductivity* σ_t of the Flysch, using the formulas

$$(h_1 + h_2)\sigma_l = h_1\sigma_1 + h_2\sigma_2, \tag{3.1}$$

$$(h_1 + h_2)/\sigma_t = h_1/\sigma_1 + h_2/\sigma_2. \tag{3.2}$$

The conductivities σ_l and σ_t are nothing but the longitudinal and transverse conductivities of a single bed made up of micro-anisotropic material of a total thickness equal to that of the two strata and offering exactly the same possibility of propagation to the longitudinal current lines and the same resistance to the penetration of the transverse lines of current. Hence, a definition of the coefficient of macro-anisotropy by the formula (1.2) is given by:

$$\theta^2 = \frac{(h_1\sigma_1 + h_2\sigma_2)(h_1/\sigma_1 + h_2/\sigma_2)}{(h_1 + h_2)^2}. \tag{3.3}$$

4. TOTAL ANISOTROPY

The strata constituting the Flysch can themselves be micro-anisotropic, with coefficients of micro-anisotropy θ_1 and θ_2. In such case, micro- and macro-anisotropic phenomena are superimposed. A larger total anisotropy ensues:

$$\theta^2 = \frac{(h_1\theta_1\sigma_1 + h_2\theta_2\sigma_2)(h_1\theta_1/\sigma_1 + h_2\theta_2/\sigma_2)}{(h_1 + h_2)^2}. \tag{4.1}$$

Should the micro-anisotropies be equal:

$$\theta_1 = \theta_2 = \theta_\mu,$$

and calling θ_M the macro-anisotropy as defined by equation (3.3), we have:

$$\theta = \theta_\mu\theta_M. \tag{4.2}$$

The formula is still valid to a good approximation when σ_1 and σ_2 are very different and θ_1 differs from θ_2, provided we admit that:

$$\theta_\mu = \sqrt{\theta_1\theta_2}.$$

5. ELECTRICAL LOGGING

Theoretically, if the drill hole is infinitely narrow and the measur-

ing device infinitely short, the apparent resistivity ξ_t measured by electrical logging is coincident with the true longitudinal resistivity:

$$\xi_t = 1/\sigma_l \tag{5.1}$$

(cf., for instance: "The Anisotropy Paradox," by Maillet and Doll, cited in footnote 1).

In practice, the diameter of the hole has an appreciable size and the muds are often good conductors. Nevertheless, if we assume that the current of emission is maintained at a constant value during the run, the electrical logging operation will furnish a curve:

$$\theta\sigma = f(z), \tag{5.2}$$

θ representing the micro-anisotropy to which the minute macro-anisotropy has been added (beds of a thickness markedly smaller than the diameter of the hole); and z, the depth.

6. PSEUDO-ANISOTROPY

On the electrical logs, long sections more or less straight are sometimes encountered. They correspond to thick geological series, electrically homogeneous and generally argillaceous, for instance the Pontian in Roumania or the Helvetian in Western Morocco. But, much more often, the electrical logs have the appearance of a marked sawtooth profile. The conductivity, then, is a very complicated function of the geological level. Although its rapid variations with the depth do not have a sufficient regularity to justify the use of the term macro-anisotropy, it is, however, axiomatic that results of a similar nature will be observed. Such heterogeneous series, we might say, possess a *pseudo-anisotropy*. This concept will be discussed in greater detail in the following paragraphs.

7. DAR ZARROUK PARAMETERS[3]

In the relation between a micro-anisotropic and the corresponding isotropic layer (cf. paragraph 2), the following quantities remain unchanged:

[3] This name may appear strange, but the author has the following explanation to offer for its choice: While he was a war prisoner and pondering on these problems, he could not recall without emotion the walks which he took in the neighborhood of Tunis, and during which for the first time his views on the subject were becoming clearer while he was explaining them to a friend.

the product of the thickness by the transverse resistivity, on the one hand

$$h(\theta/\sigma) = (\theta h)(1/\sigma),$$

the product of the thickness by the longitudinal conductivity, on the other

$$h(\theta\sigma) = (\theta h)\sigma.$$

By virtue of equations (3.1) and (3.2), the same holds for the correspondence between macro-anisotropic strata of the Flysch type and the equivalent homogeneous micro-anisotropic formation.

This double remark leads to the conclusion that the two above products are capable of characterizing a bed or a geological series still better and more conveniently than its thickness, its average conductivity, and its anisotropy do. Therefore, we are led to consider the integrals:

$$R(z) = \int_0^z \frac{\theta(z)}{\sigma(z)}\,dz, \tag{7.1}$$

which we shall call the *Dar Zarrouk variable*, or the *transversal unit resistance*, and

$$C(z) = \int_0^z \theta(z)\sigma(z)dz, \tag{7.2}$$

which we shall call the *Dar Zarrouk function* or the *longitudinal unit conductance.*

If we consider a geological column built on a square unit (Fig. 2), R measures the resistance to the lines of current perpendicular to the strata, and C is the conductance offered to the lines of current parallel thereto.

In formulas (7.1) and (7.2), θ represents the micro-anisotropy (increased, as the case may be, by the fine macro-anisotropy caused by thin beds so minute that they cannot be differentiated by electrical logging). If the distribution laws,

$$\sigma = f_1(z), \tag{7.3}$$

$$\theta = f_2(z), \tag{7.4}$$

of the average conductivity σ and anisotropy θ along the geological

column are known, R (z) and $C(z)$ can be computed, and hence the Dar Zarrouk curve,

$$C = f_3(R), \tag{7.5}$$

can be traced.

Inversely, knowing the Dar Zarrouk curve, is it possible to deduce

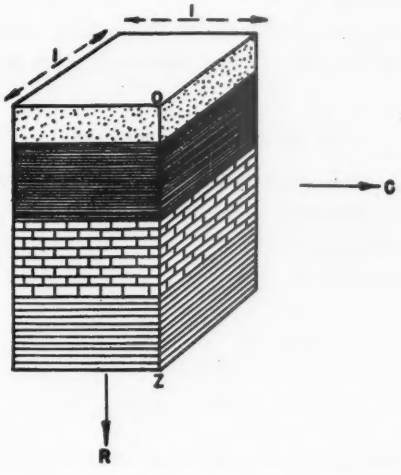

FIG. 2. Illustrating the transversal unit resistance and the longitudinal unit conductance.

the two curves (7.3) and (7.4)? The answer is generally in the negative. Writing

$$C' = \frac{dC}{dR} = f_3'(R), \tag{7.6}$$

we have

$$\sigma(z) = \sqrt{C'}, \tag{7.7}$$

and

$$u = \int_0^R \theta(z)dz = \int_0^R \sqrt{C'}\, dR. \tag{7.8}$$

We therefore do obtain the conductivity σ but we do not obtain separately the depth z and the anisotropy θ. We can merely know the *apparent depth* u, i.e., the depth in the corresponding isotropic medium.

This, evidently, is the direct consequence of the fundamental theorem of paragraph 2.

If the Dar Zarrouk curve does not describe completely the properties of the subsoil, it gives on the other hand everything which is necessary and sufficient to compute, in the case of horizontal strata, the distribution of the surface potentials and hence the form of the electrical sounding diagrams.

Conversely, the interpretation of the latter will permit the construction of the Dar Zarrouk curve. However, this is as far as one will be able to go.

8. PSEUDO-PARAMETERS

For the Dar Zarrouk parameters we can substitute the following:

Θ, the pseudo-anisotropy (a number)

Γ, the pseudo-conductivity,

as given by the equations:

$$R(z) = \frac{\Theta(z)}{\Gamma(z)}\, z, \tag{8.1}$$

$$C(z) = \Theta(z) \cdot \Gamma(z) \cdot z, \tag{8.2}$$

which consists actually in computing averages out of equations (7.1) and (7.2). From the equations (8.1) and (8.2), we obtain:

$$\Theta z = \sqrt{CR}, \tag{8.3}$$

$$\Gamma = \sqrt{C/R}, \tag{8.4}$$

which should be compared to equations (7.7) and (7.8). The latter can be written:

$$du = \theta dz = \sqrt{dC \cdot dR},$$

$$\sigma = \sqrt{dC/dR},$$

The product $z\Theta$ can be called *pseudo-depth*, and it must not be confused with the apparent depth u.

The interest of these pseudo-parameters is that they allow a common representation of the Dar Zarrouk curve together with the electrical logging diagram $\theta\sigma = f(z)$ and the electrical sounding graph $\xi = f(\rho)$. Lengths are figured in abscissae, conductivities or resistivities in ordinates (conductivities, downwards; resistivities, upwards). Scales are logarithmic, as customary (Fig. 3).

The running point Z, of the Dar Zarrouk curve can be designated

at will by (1) its coordinates in the system of the horizontal axis of the pseudo-depths and the vertical axis of the pseudo-conductivities; or (2) its coordinates in the diagonal axes, with the *R*-axis running along the first bisector and the *C*-axis along the second bisector.

It must be kept in mind, however, that on these diagonal axes, the module of the logarithmic scales is $\sqrt{2}$-times smaller.

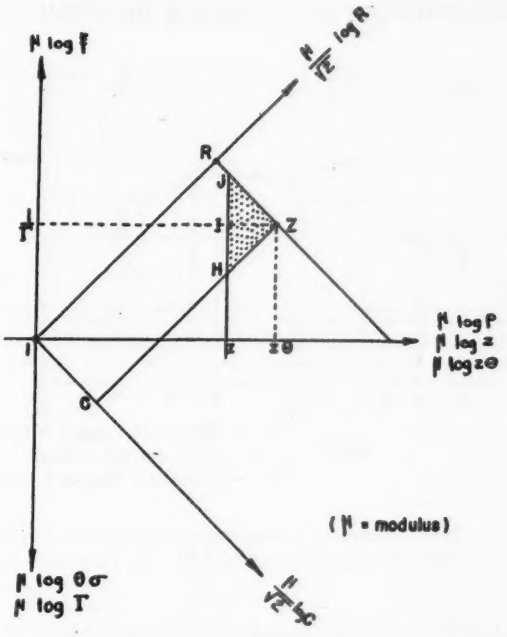

FIG. 3. Double representation of the Dar Zarrouk parameters.

9. PSEUDO-ANISOTROPY TRIANGLE

The shaded triangle marked on Figure 3 is limited by the vertical z and by the diagonals C and R. Its furthermost apex to the right Z is the Dar Zarrouk point (coordinates C and R); its lowermost apex H is the Hummel point (coordinates z and C); the horizontal length ZI measures the pseudo-anisotropy Θ (or, rather, its logarithm).

10. EXAMPLES

(a) Figures 4 and 5 give two examples of the simultaneous representation on the same logarithmic paper of (1) the electrical logging

diagram; (2) the Dar Zarrouk curve; and (3) the electrical sounding graph in horizontal stratification.

Between the two latter curves there already appears quite a close relation. From an electrical logging diagram, squarely indented after the pattern of a Greek fret, we obtain a Dar Zarrouk curve, already simplified and smoothed. Instead of discontinuities we obtain only angular points. Thence, we pass to an electrical sounding graph which shows a further smoothing of the shape of the silhouette.

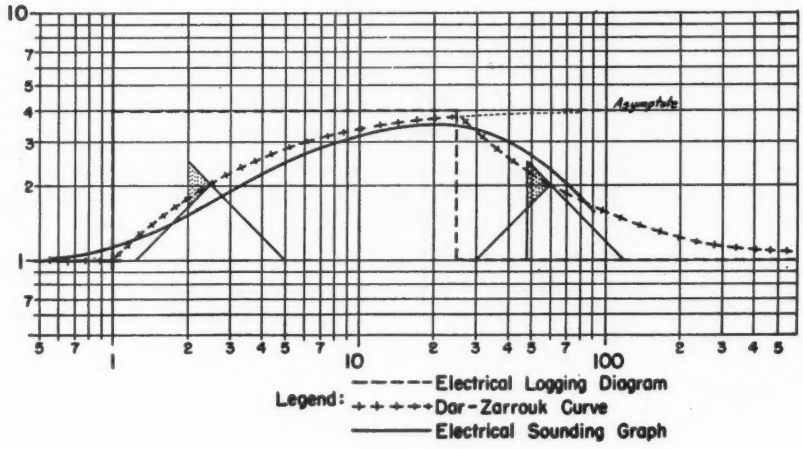

FIG. 4. Example of a simultaneous representation of the electrical-logging diagram, the electrical-sounding graph and the Dar Zarrouk curve.

Figure 4 corresponds to a thick bed (from $z=1$ to $z=25$) not very differentiated ($1/\sigma=4$) from the overburden and the substratum, which are of the same material ($1/\sigma=1$).

Figure 5, on the other hand, corresponds to an overburden from $z=0$ to $z=1$ for which $\sigma=1$, then a highly conductive layer from $z=1$ to $z=2$ for which $\sigma=39$, and below this a non-conductive basement.

In these two examples, it is assumed that there is no micro-anisotropy ($\theta=1$). The apparent depth u, therefore, is equal to the actual depth, z. Notwithstanding, there appears a marked pseudo-anisotropy Θ (it is even great in Figure 5), and the pseudo-depth $z\Theta$ is always greater than the depth z.

(b) For the surface layer, we have:

$$d[\log C]/d[\log R] = 1,$$

and the first branch of the Dar Zarrouk curve is the horizontal line

$$\Gamma = 1. \tag{10.1}$$

The following branches are all curved. The angle of the tangent to the Dar Zarrouk curve is given by the formula

$$-\left[d(\log \Gamma)\right]/\left[d(\log z\Theta)\right] = (\Gamma^2 - \sigma^2)/(\Gamma^2 + \sigma^2). \tag{10.2}$$

On each branch of the Dar Zarrouk curve, the ordinate Γ tends

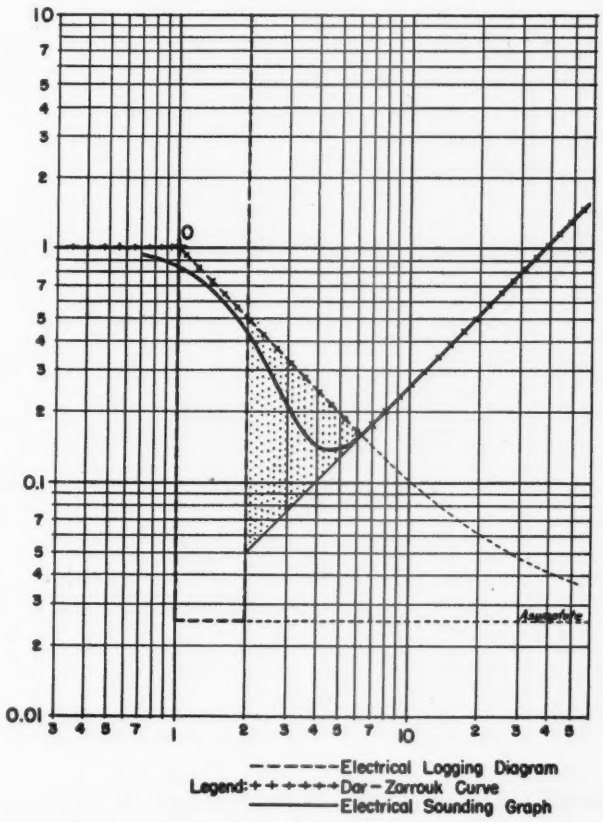

FIG. 5. Example of a simultaneous representation of the electrical-logging diagram, the electrical-sounding graph and the Dar Zarrouk curve.

progressively towards σ. The concavity is downwards for the ascending branches, and vice versa.

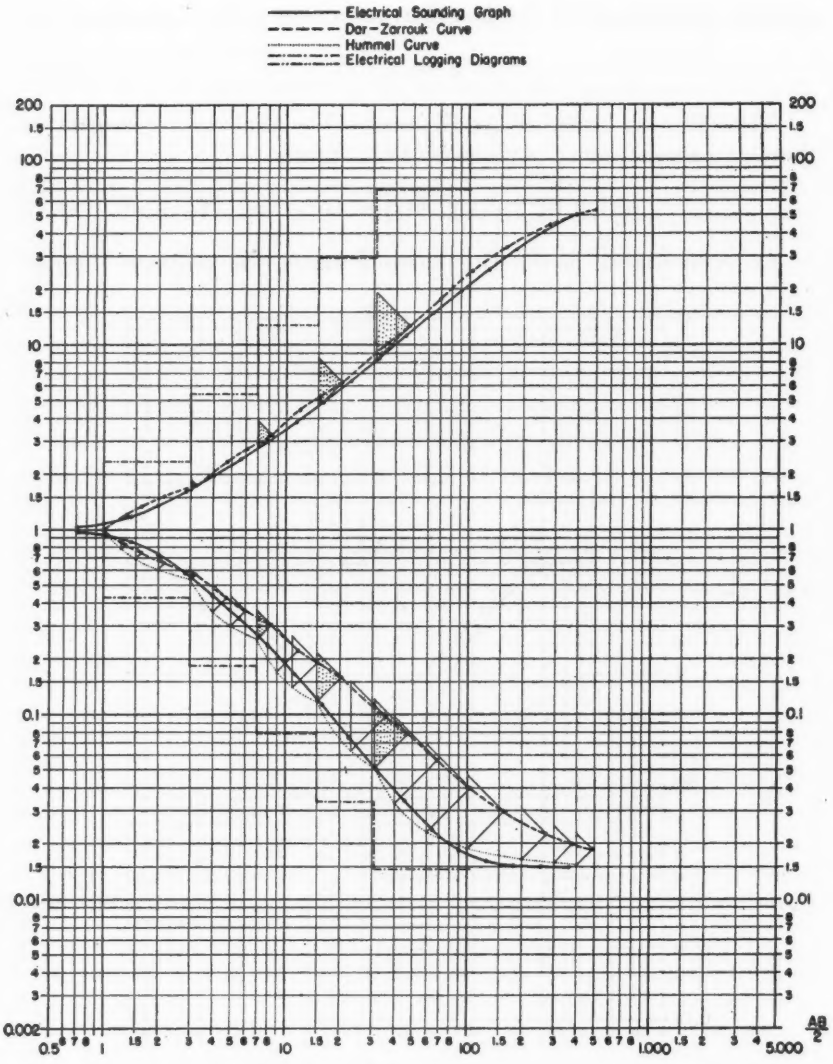

FIG. 6. Example of a simultaneous representation of the electrical-logging diagram, the electrical-sounding graph, the Dar Zarrouk curve and the Hummel curve.

(c) Figures 6 and 7 offer two other examples of much more complicated cases (6 and 7 different layers) of simultaneous representations on the same logarithmic scale of:

(1) the electrical logging diagram;

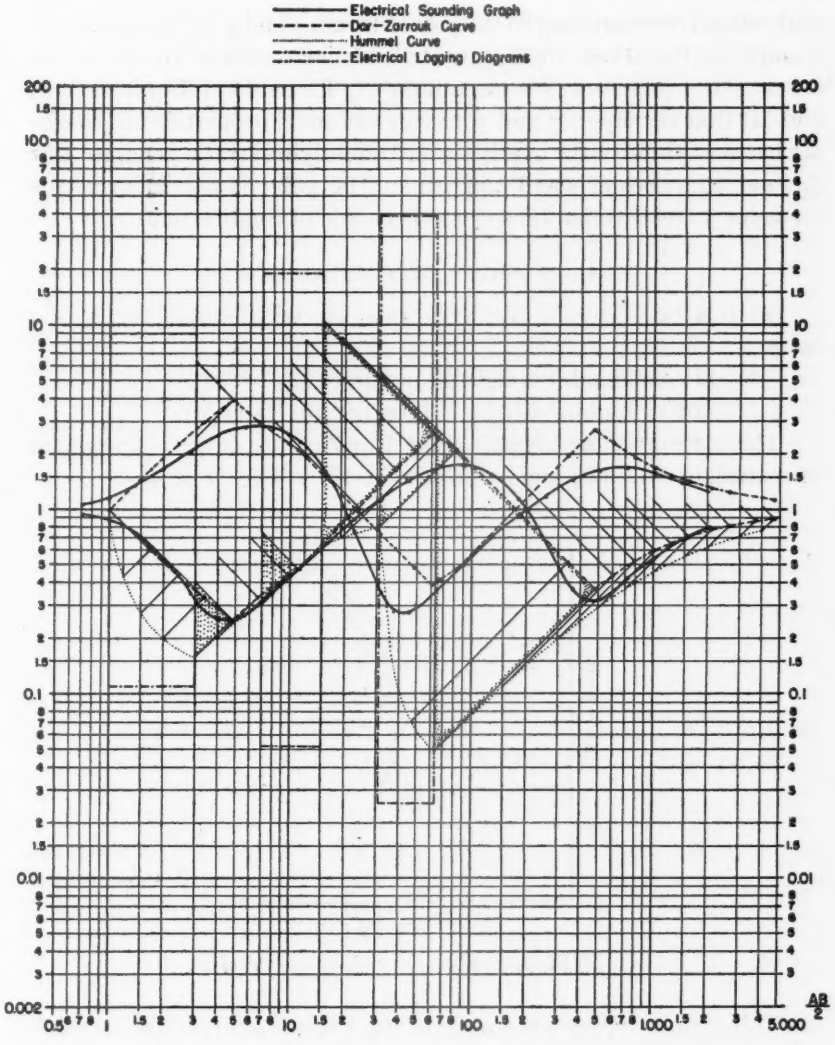

FIG. 7. Example of a simultaneous representation of the electrical-logging diagram, the electrical-sounding graph, the Dar Zarrouk curve and the Hummel curve.

(2) the Dar Zarrouk curve;

(3) the electrical sounding graph in horizontal stratification.

The parallelism between the Dar Zarrouk curve and the electrical sounding graph is clearly apparent.

On Figure 7, we shall note: (1) that the branches of the Dar Zar-

rouk curve corresponding to the pair of layers 3 and 4 on the one hand, 5 and 6 on the other, are almost straight lines, parallel to one or the other of the bisectors (see paragraph 11, Principle of Equivalence); and (2) that the layers 3 and 5, having electrical properties intermediate between those of the overlying and underlying strata, generate Dar Zarrouk branches of small amplitude. The point is particularly true for layer 5 (refer to paragraph 12, Principle of Suppression).

11. PRINCIPLE OF EQUIVALENCE

(a) If a bed (h, σ, θ) is a very good electrical conductor, it is a factor:

of considerable weight in integral $C(\Delta C = \theta h \sigma)$,

and of minute weight in integral $R(\Delta R = \theta h/\sigma)$.

The corresponding branch of the Dar Zarrouk curve is a segment of a straight line AB, almost parallel to the C-axis (Fig. 8).

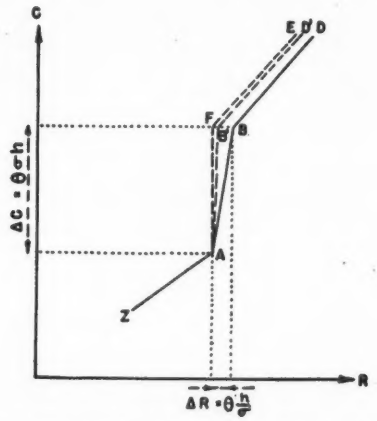

FIG. 8. Illustrating the principle of equivalence.

If the conductivity σ is multiplied by a factor $\alpha > 1$, while the thickness h is divided by α, the considerable weight of ΔC remains unchanged but the minute weight of ΔR becomes α^2 smaller still.

The Dar Zarrouk curve shifts from $ZABD$ to $ZAB'D'$ and is but very slightly modified. At the limit $(\alpha \to \infty)$ it reaches the position $ZAFE$. Mathematically speaking, this last curve corresponds to a *conductive film* $(h = 0, \sigma = \infty, \theta h \sigma = \Delta C)$.

Now it has been pointed out already (end of paragraph 7), and it will be demonstrated below, that the knowledge of the Dar Zarrouk

curve is sufficient to determine the potential distribution at the surface. Therefore, the different conductive beds (θ, h, σ), $(\theta, h/\alpha, \alpha\sigma)$, which give the almost coincident curves $ZABD$, $ZAB'D'$, will furnish electrical sounding graphs which are almost identical. They will often differ from each other by quantities inferior to the errors in measurement. They are all equivalent among themselves, and equivalent, for that matter, to the film $\Delta C = \theta h \sigma$. *The interpretation of the electrical sounding graphs will not furnish the thickness of a very conductive bed,* but will give only its longitudinal unit of conductance ΔC.

(b) In the same manner, *in the case of a very resistive bed, electrical prospecting will not furnish the means of measuring its thickness but will allow only the determination of transversal unit resistance* ΔR.

(c) This is the principle of equivalence, which had been mentioned many years ago by H. G. Doll. The consequent indeterminateness will be eliminated if by another technique (electrical logging, generally) it is possible to know beforehand the conductivity of the bed in question.

If so, its thickness will be known by the formula:

$$h = \Delta C/\theta\sigma \text{ (conductive bed)}$$

$$h = (\sigma/\theta)\Delta R \text{ (resistive bed).}$$

In the case of a conductive bed, electrical logging gives precisely the product $\theta\sigma$. On the other hand, the very resistive formations, therefore not argillaceous, are not micro-anisotropic, as a rule.

(d) Of course, the principle of equivalence does not apply if the thickness h of the beds is very great. In fact, the equivalence holds fully for very aberrant beds, as long as their thickness does not exceed their distance (from the top) to the surface.

12. PRINCIPLE OF SUPPRESSION[4]

(a) If a bed, even rather thick, lies between two other formations, one much more conductive and the other one much more resistant, it calls for a small branch BC (Fig. 9) on the Dar Zarrouk curve. Such a branch is negligible, compared to the more important branches AB and CD corresponding to the surrounding media.

Had this intermediate bed been absent, the Dar Zarrouk curve

[4] Marcel Schlumberger and Raymond Maillet, *L'evolution des problemes et des methodes de la geophysique appliquee,* Deuxieme Congres Mondial du Petrole (Paris, June, 1937), Edition de la Revue Petrolifere.

would be *ZABD'E'* instead of *ZABCDE*, and the disturbance would be small.

Furthermore, it would have been necessary to add very little to the thickness of the underlying and overlying beds to obtain a Dar Zar-

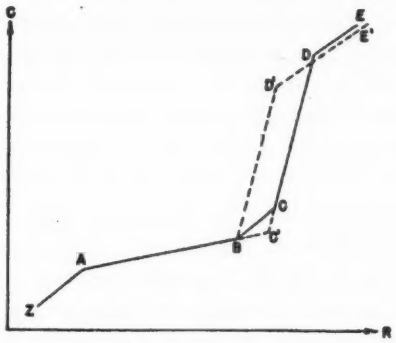

FIG. 9. Illustrating the principle of suppression.

rouk curve such as *ZABC'DE* which is almost coincident with *ZABCDE*. Between these two curves, the difference is so slight that the corresponding distributions of the surface potentials (and with them the electrical sounding graphs) are practically the same. The interpretation will not, therefore, allow one to suspect the existence of the intermediate layer *BC*. Thus is the principle of suppression, the consequences of which are important.

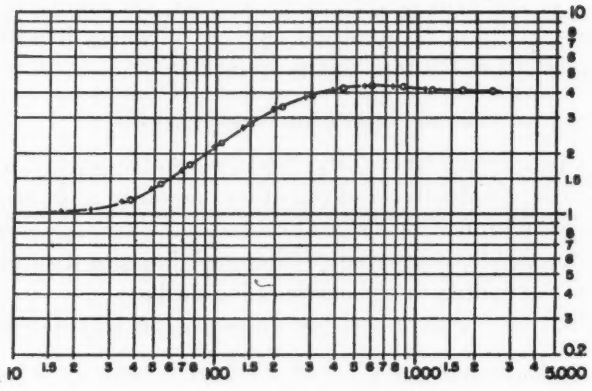

FIG. 10. Practical example of suppression.

(b) Figure 10 gives a striking example of suppression. It represents the electrical sounding graphs obtained with the two following sequences:

Resistivities $\frac{1}{\sigma}$	Thicknesses h for curves marked by	
	+	○
1	34	38
4	17	0
16	34	38
4	∞	∞

The two curves which are marked respectively by small crosses and circles are strictly coincident. Their coincidence is even better than the graphic representations allow the reader to see.

13. FIRST FORM OF THE EQUATION OF PROSPECTING

(a) The electrical field $\boldsymbol{E}$ results from a scalar potential V:

$$\boldsymbol{E} = -\operatorname{grad} V. \tag{13.1}$$

Ohm's law ties this field to the current density $\boldsymbol{I}$:

$$\boldsymbol{I} = \sigma \boldsymbol{E}. \tag{13.2}$$

Finally the law of conservation of electricity is written:

$$\operatorname{div} \boldsymbol{I} = 0, \tag{13.3}$$

with the exception of the current electrodes.

Eliminating $\boldsymbol{E}$ and $\boldsymbol{I}$ between these three equations, we obtain a single equation in V and σ. This is the equation of prospecting.

For a horizontal stratification it is assumed that there is a single current electrode at a finite distance. (The case of several electrodes would be solved by merely adding the potentials corresponding to each of them.) This single electrode is taken as the origin of a system of coordinates. Obviously, cylindrical coordinates are chosen, with a vertical z-axis oriented downwards. The conductivity σ is only a function of the depth z. The equation of prospecting can then be written

$$\frac{\partial^2 V}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial V}{\partial \rho} + \frac{1}{\theta^2}\frac{\partial^2 V}{\partial z^2} + \frac{1}{\theta^2}\frac{\partial V}{\partial z}\cdot\frac{d(\log \sigma/\theta)}{dz} = 0, \tag{13.4}$$

an expression which is relatively involved and which depends explicitly from θ the micro-anisotropy. This factor can be eliminated, by substituting the apparent depth u for the true depth z,

$$\frac{\partial^2 V}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial V}{\partial \rho} + \frac{\partial^2 V}{\partial u^2} + \frac{\partial V}{\partial u}\cdot\frac{d \log \sigma}{du} = 0. \tag{13.5}$$

(b) *However, if we choose as a third coordinate, not the depth z or the apparent depth u, but the Dar Zarrouk variable R, the equation of prospecting is further simplified* and takes the form:

$$\frac{1}{\rho}\cdot\frac{\partial}{\partial \rho}\left(\rho\,\frac{\partial V}{\partial \rho}\right) + \frac{1}{C'}\,\frac{\partial^2 V}{\partial R^2} = 0. \tag{13.6}$$

If we look for integrals of the type:

$$V = J(\rho)S(R), \tag{13.7}$$

by the method of separation of variables, we obtain a Bessel equation:

$$\frac{d^2 J}{d\rho^2} + \frac{1}{\rho}\frac{dJ}{d\rho} + \lambda^2 J = 0, \tag{13.8}$$

and a linear equation of the second order in its canonic form

$$\frac{d^2 S}{dR^2} - \lambda^2 C' S = 0, \tag{13.9}$$

with the invariant $-\lambda^2\sigma^2$ (according to equation 7.7).

The micro-anisotropy θ has disappeared in the new form of the equation of prospecting. On the other hand, formula (13.6) shows that the surface potentials depend only upon the Dar Zarrouk curve

$$C = f_3(R), \tag{7.5}$$

and not of the two curves:

$$\sigma = f_1(z), \tag{7.3}$$

$$\theta = f_2(z). \tag{7.4}$$

Thus the result announced at the end of paragraph 7 and utilized in paragraphs 11 and 12 is demonstrated.

(c) One can obtain equation (13.6) out of the classical equation (13.4) by merely using the transformation of variable,

$$\theta dz = \sqrt{C'}\,dR. \tag{7.8}$$

(d) Employing the symbols of tensor calculus, the electrical field is a co-variant vector:

$$E_k = -\frac{\partial V}{dx^k}.$$

The conductivity is a contra-variant tensorial density σ^{ik}, and the current density is a vectorial density I^i. Ohm's law can be written:

$$I^i = \sigma^{ik} E_k,$$

and the equation of prospecting becomes:

$$\frac{\partial}{\partial x^i}\left(\sigma^{ik}\frac{\partial V}{\partial x^k}\right) = 0. \tag{13.10}$$

From this general form it is very easy to deduce equation (13.6) in the particular case of horizontal strata.

14. SECOND FORM OF THE EQUATION OF PROSPECTING

(a) In d.-c. current, the Maxwell-Ampere formula:

$$\text{curl } \boldsymbol{M} = 4\pi \boldsymbol{I} \tag{14.1}$$

expresses that the magnetic field $\boldsymbol{M}$ is (disregarding the factor 4π) the potential vector of the current density $\boldsymbol{I}$. Ohm's law connects the latter to the electrical field:[5]

$$\boldsymbol{E} = \rho \boldsymbol{I}. \tag{14.2}$$

Finally this electrical field possesses a scalar potential

$$\text{curl } \boldsymbol{E} = 0. \tag{14.3}$$

Eliminating $\boldsymbol{E}$ and $\boldsymbol{I}$ between these three formulas, we obtain a vectorial equation in $\boldsymbol{M}$, which is the equation of prospecting under its second form.

(b) This vectorial equation is equivalent, in general, to the three ordinary equations corresponding to the three components of $\boldsymbol{M}$.

But, precisely, in the case of a single electrode in horizontal formations, for symmetry reasons, the lines of the magnetic field are circles centered on the vertical of the electrode. The radial and vertical components of $\boldsymbol{M}$ are equal to 0. One single equation remains, which

[5] This resistivity ρ is not to be mistaken for the radius vector ρ which appears in the following equation.

gives the tangential component $M\phi$ or the modulus M of the field, which is the same thing.

(c) Let us consider a given point P of the subsoil (see Fig. 11); let C be the line of magnetic force, and OF be the line of current passing through this point. The latter is the generatrix of a revolution surface around Oz constituting a current surface N. Also, let us call:

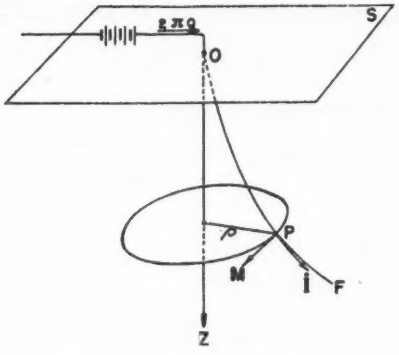

FIG. 11. Relationship between electrical data at a given point of the subsoil.

$2\pi Q$, the total current sent into the ground by electrode O (Q = emissivity of O);

W, the part of this current that passes above surface N;

$1-W$, the part of this current that passes inside surface N.

Integrating the Maxwell-Ampere formula and applying the Stokes formula around circle C, we obtain:

$$2\pi\rho M = 4\pi \cdot 2\pi Q(1 - W),$$

or[6]

$$H = \rho M = 4\pi Q(1 - W). \qquad (14.4)$$

(d) At the surface:

$$W = 0,$$

$$M = \frac{4\pi Q}{\rho}.$$

The superficial magnetic field is, therefore, the same as if all the current were concentrated along the Oz axis. It is not influenced by the

[6] We recognize in $H=\rho M$ the co-variant component of the magnetic field in terms of tensorial calculus.

distribution of the underground electrical properties of a horizontally-stratified medium and cannot, therefore, be utilized for prospecting. This result had already been demonstrated by Sabba S. Stefanesco.[7]

(e) The equation of prospecting deduced from formulas (14.1), (14.2), and (14.3), in the case of a single electrode and horizontal stratification can be written:

$$\frac{\partial^2 H}{\partial \rho^2} - \frac{1}{\rho}\frac{\partial H}{\partial \rho} + \frac{1}{\theta^2}\frac{\partial^2 H}{\partial z^2} - \frac{1}{\theta^2}\frac{d(\log \theta\sigma)}{dz}\cdot\frac{\partial H}{\partial z} = 0, \quad (14.5)$$

or also,

$$\frac{\partial^2 H}{\partial \rho^2} - \frac{1}{\rho}\frac{\partial H}{\partial \rho} + \frac{\partial^2 H}{\partial u^2} - \frac{d(\log \sigma)}{du}\cdot\frac{\partial H}{\partial u} = 0. \quad (14.6)$$

Introducing the Dar Zarrouk function C, we bring this equation of prospecting to the simpler form:

$$\rho\frac{\partial}{\partial \rho}\left(\frac{1}{\rho}\cdot\frac{\partial H}{\partial \rho}\right) + \frac{1}{R'}\frac{\partial^2 H}{\partial C^2} = 0, \quad (14.7)$$

with of course:

$$R' = \frac{dR}{dC} = \frac{1}{\sigma^2}\cdot \quad (14.8)$$

The analogy between (13.6) and (14.7) is evident. If in (14.7), we replace H by ρM, according to (14.4), we obtain

$$\frac{\partial^2 M}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial M}{\partial \rho} - \frac{M}{\rho^2} + \frac{1}{R'}\frac{\partial^2 M}{\partial C^2} = 0. \quad (14.9)$$

If we try to find integrals of the type:

$$M = K(\rho)T(C), \quad (14.10)$$

by the method of separation of variables, we obtain a modified Bessel equation:

$$\frac{d^2 K}{d\rho^2} + \frac{1}{\rho}\frac{dK}{d\rho} - \left(\mu^2 + \frac{1}{\rho^2}\right)K = 0, \quad (14.11)$$

[7] Sabba S. Stefanesco, en collaboration avec C. et M. Schlumberger, "Etudes sur la Prospection Electrique du sous-sol." Premiere Serie, Institutul Geologic al Romaniei, Imprimerie Nationale, Bucuresti, 1929.

and a linear equation of the second order in its canonic form:

$$(d^2T/dC^2) + \mu^2 R' T = 0, \tag{14.12}$$

with the invariant $+(\mu^2/\sigma^2)$.

(f) Employing the notations of the tensor calculus, the magnetic field is a co-variant vector M_l, or rather, an anti-symmetric tensorial density H^{ik},

$$H^{ik} = M_l \text{ (permutations } ikl \text{ even)}.^{8}$$

The current density I^i is a vectorial density.[9]

$$\frac{\partial H^{ik}}{\partial x^k} = 4\pi I^i$$

The resistivity is a symmetrical tensorial capacity ρ_{il}

$$E_l = \rho_{il} I^i$$

and the general form of the equation of prospecting can be written:

$$\frac{\partial}{\partial x^m}\left[\rho_{il}\frac{\partial H^{ik}}{\partial x^k}\right] = \frac{\partial}{\partial x^l}\left[\rho_{im}\frac{\partial H^{ik}}{\partial x^k}\right]. \tag{14.13}$$

15. REMARKS

When the law $\sigma(z)$ is known and one wants to deduce the superficial potential $V(\rho, 0)$, one can start from either form of the equation of prospecting.

(a) The French school of geophysics with C. and M. Schlumberger, Sabba S. Stefanesco, V. A. Kostitzin, and the engineers of the Compagnie Generale de Geophysique, have mostly applied the first form,[10,11,12]

[8] On the equivalence in tri-dimensional space between antisymmetric tensorial density and co-variant vector, see, for instance, Leon Brillouin, "Les tenseurs en mecanique et en elasticité," Chapter III, pp. 50–52, Masson, Paris, 1938.

[9] Cf., for example E. Madelung, "Die mathematischen Hilfsmittel des Physikers," 3. Auflage, p. 278, J. Springer, Berlin, 1936.

[10] S. Stefanesco et C. et M. Schlumberger, *Sur la distribution electrique potentielle autour d'une prise de terre ponctuelle dans un terrain a couches horizontales, homogenes et isotropes*, Le Journal de Physique et le Radium, Serie VII, Vol. 4, pp. 132–141, April 1930.

[11] Sabba S. Stefanesco en collaboration avec C. et M. Schlumberger, *Etudes theoriques sur la prospection electrique du sous-sol*, Deuxieme Serie, pp. 80–115, Institutul Geologic al Romaniei, Imprimerie Nationale, Bucuresti, 1932.

[12] V. A. Kostitzin, *Sur l'equation de Laplace dans un milieu stratifié*, Prace Matematyczno-Fizyczne, Warsaw, 1935.

$$\frac{\partial^2 V}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial V}{\partial \rho} + \frac{\partial^2 V}{\partial u^2} + \frac{d(\log \sigma)}{du}\frac{\partial V}{\partial u} = 0, \qquad (13.5)$$

and their research work is essentially based on the formula

$$\int_0^\infty J_0(\lambda\rho)e^{-\lambda|z|}d\lambda = 1/\sqrt{\rho^2 + z^2} \qquad (15.1)$$

J_0 representing the Bessel function of the first kind and of order 0.

(b) Professor Louis V. King[13,14] is the one who to our knowledge was the first to study the second form of the equation of prospecting:

$$\frac{\partial^2 W}{\partial \rho^2} - \frac{1}{\rho}\frac{\partial W}{\partial \rho} + \frac{\partial^2 W}{\partial u^2} - \frac{d(\log \sigma)}{du}\frac{\partial W}{\partial u} = 0, \qquad (14.6)$$

or

$$\rho\frac{\partial}{\partial \rho}\left(\frac{1}{\rho}\frac{\partial W}{\partial \rho}\right) + \sigma\frac{\partial}{\partial z}\left(\frac{1}{\sigma}\frac{\partial W}{\partial z}\right) = 0, \qquad (15.2)$$

without taking the micro-anisotropy (therefor $u=z$) into account, and calling W (which he wrote ψ) the "electrical current function."

The development of this second method is, actually, based on the formula

$$\frac{2}{\pi}\int_0^\infty K_0(\mu\rho)\cos \mu z\, d\mu = 1/\sqrt{\rho^2 + z^2} \qquad (15.3)$$

K_0 representing the modified cylinder function of the third kind and of order 0.[15]

[13] Louis V. King, *On the Flow of Electric Current in Semi-Infinite Stratified Media*' Proceedings of the Royal Society, Series A, Vol. 137, pp. 237–277, London, 1933.

[14] Louis V. King, *On the Flow of Electric Current in Semi-Infinite Media in Which the Specific Resistance is a Function of the Depth*, Philosophical Transactions of the Royal Society, Series A, Vol. 233, pp. 327–359, London, 1934.

[15] It is the function K as defined in the "Treatise of Bessel Functions" of Gray and Mathews, and in the "Formulaire pour le calcul symbolique" by N. W. McLachlan and Pierre Humbert. With the notations of the "Funktionentafeln" of Jahnke and Emde, we have:

$$\frac{2}{\pi}K_0(x) = jH_0^{(1)}(jx),$$

$$\frac{2}{\pi}K_1(x) = -H_1^{(1)}(jx).$$

(c) Between the two processes the bridge is established by the Mehler integral

$$K_0(\mu\rho) = \int_0^\infty J_0(\lambda\rho)\,\frac{\lambda}{\lambda^2+\mu^2}\,d\lambda, \tag{15.4}$$

and by the development in series after Mittag Leffler of fractions of the type:

$$(\sinh \lambda m)/(\cosh \lambda m - \cos c).$$

All of these points will be developed in a subsequent note.

16. REDUCED APPARENT RESISTIVITIES

(a) For a single electrode sending a current $2\pi Q$ in a homogeneous ground of conductivity σ_0, the potential and the field at the surface are given by the formulas:

$$V(\rho\cdot o) = Q/(\sigma_0\rho), \tag{16.1}$$

$$E(\rho\cdot o) = Q/(\sigma_0\rho^2). \tag{16.2}$$

Coming back to the case of a stratified ground, and calling σ_0 the superficial conductivity:

$$\sigma_0 = \lim_{z\to 0} \sigma(z),$$

we are led to consider two functions Ψ and Ξ of the vector radius ρ which satisfy the equations:

$$V(\rho\cdot o) = \Psi[Q/(\sigma_0\rho)] \tag{16.3}$$

$$E(\rho\cdot o) = \Xi[Q/(\sigma_0\rho^2)] \tag{16.4}$$

and which both become identical to 1, should the subsoil become homogeneous ($\sigma(z)=\sigma_0$).

(b) To those functions Ψ and Ξ the Schlumberger geophysicists have given the name of "reduced apparent resistivities."

Warren Weaver[16] calls Ψ the "departure from normal potentials"; Louis V. King[17] calls Ξ the "surface gradient characteristic."

(c) Between Ψ and Ξ we have the relation:

$$\Xi = \Psi - \rho(d\Psi/d\rho). \tag{16.5}$$

[16] Warren Weaver, "Certain Applications of the Surface Potential Method," A.I.M.E. Tech. Publ. No. 121 (Class L, No. 3), 1928.

[17] *Loc. cit.*

(d) The relations between Ψ and V, and between Ξ and $\boldsymbol{E}$ are given by the initial formulas (16.3) and (16.4). Starting from the second form of the equation of prospecting, we have:

$$\Xi = -(\rho/4\pi Q)(\partial H/\partial u)_{u=0} \quad \text{or,} \tag{16.6}$$

$$\Xi = +\rho(\partial W/\partial u)_{u=0}. \tag{16.7}$$

(e) The first apparent resistivity Ψ can be expressed without difficulty within the ground as well as at the surface. We merely need to replace (16.3) by

$$V(\rho, z) = \Psi(Q/\sigma_0)(1/\sqrt{\rho^2 + z^2}). \tag{16.8}$$

17. DOUBLE DIPOLE

Quite some time back, Raymond Geneslay proposed to replace the ground electrode by a dipole with spacing ϵ, sending in the ground a current $2\pi Q$. Let us write:

$$\mathcal{M} = Q\epsilon. \tag{17.1}$$

The superficial electrical field $\boldsymbol{E}$, generated by the emitting dipole at the distance ρ is given by:

$$E = \Upsilon(2\mathcal{M})/(\sigma_0\rho^3) \tag{17.2}$$

Υ representing a third apparent resistivity

$$\Upsilon = \Xi - (\rho/2)(d\Xi/d\rho), \tag{17.3}$$

$$\Upsilon = \Psi - \rho(d\Psi/d\rho) + (\rho^2/2)(d^2\Psi/d\rho^2). \tag{17.4}$$

Geneslay's idea remained unworkable for a long time on account of the weakness of the fields developed by a dipole. Today, however, particularly for the study of telluric currents, registering potentiometers have been developed which are so sensitive that electrical prospecting can be carried out at great depth with two (one emitting, one receiving) dipoles.

APPENDIX

FUNDAMENTAL THEOREM CONCERNING ANISOTROPY

(a) Let $\mathcal{E}$ be a space in which direct currents are distributed in volume. Let us establish therein a general system of curvilinear coordinates x^1, x^2, x^3. With respect to distances, we have the fundamental metric form:

$$ds^2 = \sum_{ik} g_{ik} dx^i dx^k, \tag{1}$$

and the elementary volume unit built on the unit vectors is measured by:

$$\sqrt{g} = \sqrt{|\, g_{ik} \,|}. \tag{2}$$

The law of conservation of electricity is expressed in writing that the tensorial density I^i is without divergence.

$$\sum_i \frac{\partial I^i}{\partial x^i} = 0. \tag{3}$$

A fundamental property of the electric field E_k is that its curl is zero:

$$\frac{\partial E_i}{\partial x^k} - \frac{\partial E_k}{\partial x^i} = 0. \tag{4}$$

Finally the generalized Ohm's law is written:

$$I^i = \sum_k \sigma^{ik} E_k. \tag{5}$$

(b) This being so, let $\mathcal{E}'$ be another space, the elements of which will be distinguished by an accent. We shall establish a system of coordinates x'^1, x'^2, x'^3, with the metric form:

$$ds'^2 = \sum_{ik} g_{ik}' dx'^i dx'^k. \tag{6}$$

Let us establish a point-by-point correspondence between the two spaces. Between point $P(x^1\ x^2\ x^3)$ of $\mathcal{E}$ and point $P'(x'^1\ x'^2\ x'^3)$ of $\mathcal{E}'$ let us have:

$$x'^1 = x^1; \qquad x'^2 = x^2; \qquad x'^3 = x^3. \tag{7}$$

In space $\mathcal{E}'$ we shall establish a tensorial density field σ'^{ik}, a vectorial density field I'^i, and a vector field E'^k so that for two corresponding points P and P' we shall have:

$$\sigma'^{ik} = \sigma^{ik}, \tag{8}$$

$$I'^i = I^i, \tag{9}$$

$$E_k' = E_k. \tag{10}$$

It is evident that since σ^{ik}, I^i, and E_k satisfy the laws of electrokinetic equilibrium (3), (4), and (5) in the initial space $\mathcal{E}$, the fields

σ'^{ik}, I'^{i}, and E'^{k}, will satisfy the same laws in space $\mathcal{E}'$. It is important to remark that according to (9) ,the flux of current is the same through a given surface S of space $\mathcal{E}$ and through the corresponding surface S' of the transformed space $\mathcal{E}'$. In particular, the total current sent by an electrode remains unchanged.

In the same manner, according to (10) ,the electrical potential V, at P, will be the same as the potential V' at P'.

(c) If we particularize the system of coordinates in making them triply orthogonal, we can express the physical components $\overline{\sigma^{ik}}$, $\overline{I^{i}}$, $\overline{E^{k}}$ in the following manner:[18]

$$\sigma^{ik} = \sqrt{g}\,[\overline{\sigma^{ik}}/(e_i e_k)],$$
$$I^{i} = \sqrt{g}\,(\overline{I^{i}}/e_i),$$
$$E_k = \overline{E_k}\, e_k;$$

and then:

$$\overline{\sigma'^{ik}} = \overline{\sigma^{ik}}\,(e_i'/e_i)(e'_k/e_k)\sqrt{g/g'}, \tag{11}$$
$$\overline{I'^{i}} = \overline{I^{i}}\,(e_i'/e_i)\sqrt{g/g'}, \tag{12}$$
$$\overline{E_k'} = \overline{E_k}\, e_k/e_k', \tag{13}$$
$$V' = V. \tag{14}$$

(d) Therefore, if we transform a space $\mathcal{E}$, in which there exists a certain distribution $\overline{\sigma^{ik}}$ of the conductivity and a certain electro-kinetic equilibrium $\overline{I^{i}}\,\overline{E_k}$, and if in this transformation the unit vectors e^{i}, e^{k} . . . become e'_i, e'_k . . . , there will exist in the transformed space $\mathcal{E}'$ a distribution $\overline{\sigma'^{ik}}$ of the conductivity and a state of electro-kinetic equilibrium $\overline{I'^{i}}\,\overline{E_k'}$, whereby such quantities will be determined by equations (11) to (13). The currents sent by the electrodes will remain unchanged in the transformation; also the scalar potential.

(e) Of course, the transformed space $\mathcal{E}'$ is generally anisotropic even if the initial space $\mathcal{E}$ is isotropic. Actually if we have:

$$\overline{\sigma^{ik}} = \sigma\delta^{ik},$$

the δ^{ik} representing the Kronecker symbols:

$$\delta^{ik} = \begin{cases} 1 & \text{if } i = k, \\ 0 & \text{if } i \neq k, \end{cases}$$

[18] Cf. for example Brillouin, loc. cit., eq. VII–25 and following, or Madelung, loc. cit., pp. 138 to 140.

we shall have:

$$\left.\begin{aligned}\overline{\sigma'^{11}} &= (\theta_2\theta_3/\theta_1)\sigma,\\ \overline{\sigma'^{22}} &= (\theta_3\theta_1/\theta_2)\sigma,\\ \overline{\sigma'^{33}} &= (\theta_1\theta_2/\theta_3)\sigma\end{aligned}\right\} \tag{15}$$

in which:

$$\theta_1 = e_1/e_1'; \qquad \theta_2 = e_2/e_2'; \qquad \theta_3 = e_3/e_3'; \tag{16}$$

whence:

$$\sqrt{g/g'} = \theta_1\theta_2\theta_3. \tag{17}$$

UNIVERSAL SLIDE RULE FOR LINEAR VELOCITY VS. DEPTH CALCULATIONS*

ROBERT H. MANSFIELD†

ABSTRACT

Described in detail in the main body of the paper is a circular slide rule designed to use for many calculations where the seismic velocity varies linearly with distance from a datum plane (usually horizontal), i.e., where $V = V_0 + az$. Here V_0 is the velocity at datum and a is the rate of change of velocity with respect to depth z. Table 1 lists, in the first column, data that must be given and, in the second column, what may be found from it by using the present slide rule. Except for that of line 10, all calculations are limited only by the accuracy of reading the scales, which is sufficient for most practical purposes. The calculation of line 10 is approximate only, but needs correcting over only about 5 percent of its usually used range; this correction is very simply made.

TABLE 1

Required Data	Results Read From Rule
1. V_0, a, reflection time $= T_0$	$z = (V_0/a)[\exp(aT_0/2) - 1]$
2. V_0, a, T_0	Radius of wave-front circle $= R = (V_0/a)\sinh aT_0/2$
3. V_0, a, T_0	Depth of center of wave-front circle $= h = (V_0/a)(\cosh aT_0/2 - 1)$
4. z, T_0, a	V_0
5. z, T_0, V_0	a
6. V_0, a, T_0, spread ($=\Delta x$), time move-out ($=\Delta T$)	dip (θ)
7. V_0, a, T_0, Δx, ΔT	Depth $= z - R(1 - \cos\theta)$
8. V_0, a, T_0, Δx, ΔT	Offset $= R \sin\theta$
9. V_0, a, T_0, Δx, ΔT	Rise due to dip $= R(1 - \cos\theta)$
10. V_0, a, T_0, x, $\theta = 0$	Reflection time at a distance x from the shot point $= T_x$
11. Dip and strike and angle between dip direction and direction of vertical plane	Component of dip in corresponding vertical plane
12. Etc., etc.	

INTRODUCTION

It has for some years been the practice of the company by whom the writer is employed to use special slide rules where possible in order to simplify procedure, speed operations, and to obtain flexibility

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in the use of various velocity functions for the plotting of reflection data.

The present slide rule combines and extends several of those previously used, and includes new features which simplify procedure or reduce the likelihood of error. For circular-ray paths and for the commonly encountered ranges of the instantaneous velocity function $V = V_0 + az$, the rule gives the following quantities, whether the units be feet or meters: dip, normal move-out, depth, displacement, and, for point plotting, the rise and offset. Also, the normal move-out rule can be worked backwards to fit an approximate velocity function to observed differential times from reflections, and the depth rule can similarly be used to fit an approximate velocity function to time-depth data from whatever source. The normal move-out slide rule is calibrated in both feet and meters, and, within the range provided, thus serves for converting distances from feet to meters or vice versa.

In addition a dip-projection rule is provided which gives the dip in a plane oriented a given number of degrees from that of a known true dip. This latter rule is independent of any velocity function, and is used for plotting true vertical sections using true-dip data projected to the plane of section from adjacent regions.

A brief outline of the theory is given below, with a discussion of each division of the slide rule and a summary of operational procedure.

THEORY

General.—The ordinary mathematical relationships associated with circular ray paths and with the linear-velocity function $V = V_0 + az$ are well known and have been discussed in various published articles such as those by Ewing and Leet,[1] M. Slotnick,[2] R. A. Peterson,[3] and others.

A list of several pertinent equations, assumed to be known, is given below, and reference may also be made to the illustrative sketch of Figure 1.

[1] Maurice Ewing and L. Don Leet, *Seismic Propagation Paths*, Transactions of the A.I.M.E., Geophysical Prospecting, pp. 245–262, (1932).

[2] M. M. Slotnick, *On Seismic Computations, With Applications, I,"* GEOPHYSICS, I, 9–22, No. 1 (1936).

M. M. Slotnick, *On Seismic Computations, With Applications, II,"* GEOPHYSICS, I, 299–305, No. 3 (1936).

[3] R. A. Peterson, *A Transformed Wave Front Chart*, GEOPHYSICS, VI, 74–80, No. 1, (January, 1941.)

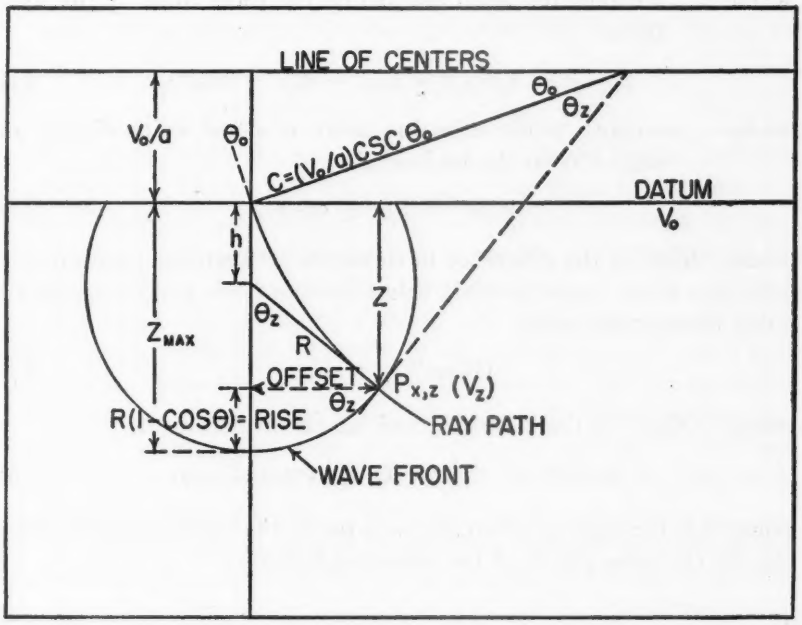

FIG. 1. Wave-front and circular-ray path relationships for the instantaneous velocity function $V=V_0+az$

These are:

$$V_z = V_0 + az, \tag{1}$$

where V_0 = initial velocity at datum surface,
z = depth of reflection point below datum,
a = rate of increase of velocity with depth.

$$h = (V_0/a)[\cosh(aT_0/2) - 1], \tag{2}$$

where h = vertical depth of the center of the wave front below the shot point at the time $T_0/2$, where T_0 = the two-way time from the datum at the shot point to the reflector and return.

$$R = (V_0/a)[\sinh(aT_0/2)], \tag{3}$$

where R = radius of the wave front from its center at depth h below datum.

$$z_{max} = h + R = (V_0/a)[\exp(aT_0/2) - 1], \tag{4}$$

where z_{max} = maximum depth reached by the wave front by the time $T_0/2$.

$$z = h + R\cos\theta = z_{max} - R(1 - \cos\theta), \tag{5}$$

where z = depth to the reflection point on a bed which dips at an angle θ from the horizontal.

$$\text{"Rise"} = R(1 - \cos\theta), \tag{6}$$

where "Rise" is the difference in elevation between the position of a reflection when "point plotted" below the shot point and when plotted using circular ray paths.

$$\text{"Offset"} = R\sin\theta, \tag{7}$$

where "Offset" is the corresponding lateral displacement.

$$\tan(\theta_z/2) = [\tan(\theta_0/2)]\exp(aT_0/2), \tag{8}$$

where θ_0 is the angle of emergence of a ray at the surface when θ_z is the dip (in the same plane) of the reflecting horizon;

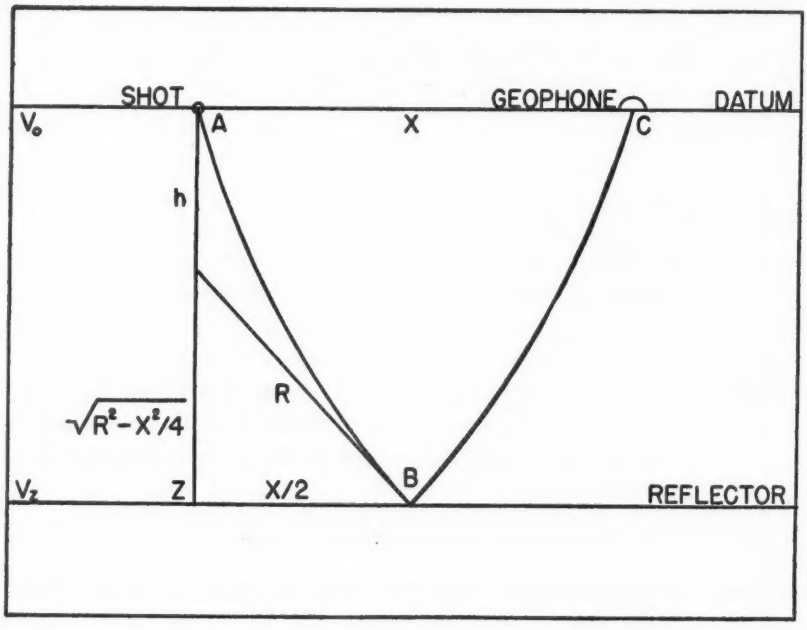

FIG. 2. Circular-ray relationships for normal move-out.

and, finally, referring to a second illustrative sketch (Fig. 2), we have

$$z = h + \sqrt{R^2 - x^2/4}, \tag{9}$$

where z is the depth of a non-dipping reflector below datum, and B is the reflection point on this reflector corresponding to a geophone at a distance x from the shot point. It is to be noted here that the time along h and R is equivalent to that along the circular ray path between the shot point and the reflection point B.

Dip Rule.—Of the above equations, we consider first equation (8) which is used in the determination of dip. For this purpose, field data are used to evaluate θ_0, and an assumed velocity distribution allows the calculation of θ_z, the dip of the reflecting bed in the line of profile.

Three general types of set-up are ordinarily used in the field, and the application of the equation to these is illustrated below, following a discussion outlined by R. A. Peterson. These types are:

(1) Shot point to shot point continuous profile spreads, with which the reflection times recorded at two successive shot points are used for the dip calculation, while full coverage correlation establishes the acceptability of the times recorded at the shot points as a measure of the dip.

(2) Split spreads, preferably symmetrical about a shot point, and with an offset which is usually small. Here the time below the shot point is used for the depth calculation, and the dip is found from the differences in arrival time of the reflection for two geophones which are usually at the spread ends, or are intermediate and symmetrical about the shot point.

(3) Single-end spreads, for which the reflection time recorded near the shot point provides a measure for the depth calculation, and the dip is figured from the difference between this time and that for some other line geophone, usually at the other end of the spread. A normal move-out correction is applied to the latter time before it is used for the dip calculation.

Figures 3, 4, and 5 depict the above arrangements, and illustrate the manner of evaluating θ_0. Figure 3 shows the case where the dip is found for two adjacent shot points. Here we assume a cross-sectional view of a vertical plane passed through two consecutive shot points which are connected and correlated by a continuous line of geophones. A plane reflector is shown, dipping at an angle θ_z from the horizontal in the plane in question.

Let us take the angle of emergence for a ray at Shot-Point 1 due to a shot from Shot-Point 1 as equal to the angle of emergence at Shot-Point 2 due to a shot from Shot-Point 2, and call the two-way time between Shot-Point 1 and the reflector T_0. We may then consider the line AB to indicate the envelope of wave fronts obtainable from any intermediate shot point for the same time T_0, and we may also assume this line AB to be perpendicular to the corresponding emergent rays.

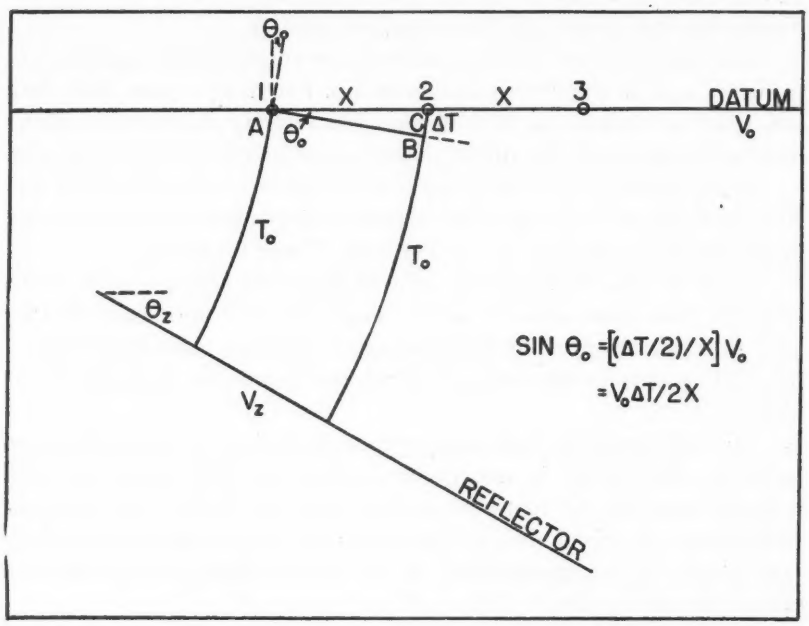

FIG. 3. Diagram for calculation of dip between shot points.

Line AB will then be at an angle θ_0 from the horizontal, and neglecting curvature of the emergent ray, it will be measured by the relation:

$$\sin \theta_0 = BC/AC = V_0 \Delta T/2X, \qquad (10)$$

where the 2 reduces ΔT to the one-way time.

For a selected $V_0/2X$, we thus determine $\sin \theta_0$, θ_0, and $\tan (\theta_0/2)$ in terms of the measured ΔT. If the field spread X differs from that chosen above as a standard, the ΔT observed for the same dip will be correspondingly larger or smaller, and can be reduced to the standard condition by a straight reduction factor which may be greater or less than one.

Passing now to the case of the split spread, we refer to Figure 4. Taking the same vertical section as in Figure 3, we consider a symmetrical split spread to be shot from Shot-Point 2 with surface coverage extending from Shot-Point 1 to Shot-Point 3, the interval between shot points being X, as before. The sub-surface coverage from reflection points P_1 to P_2 is also taken as X.

The line AB now represents the wave front for the time T_1, which

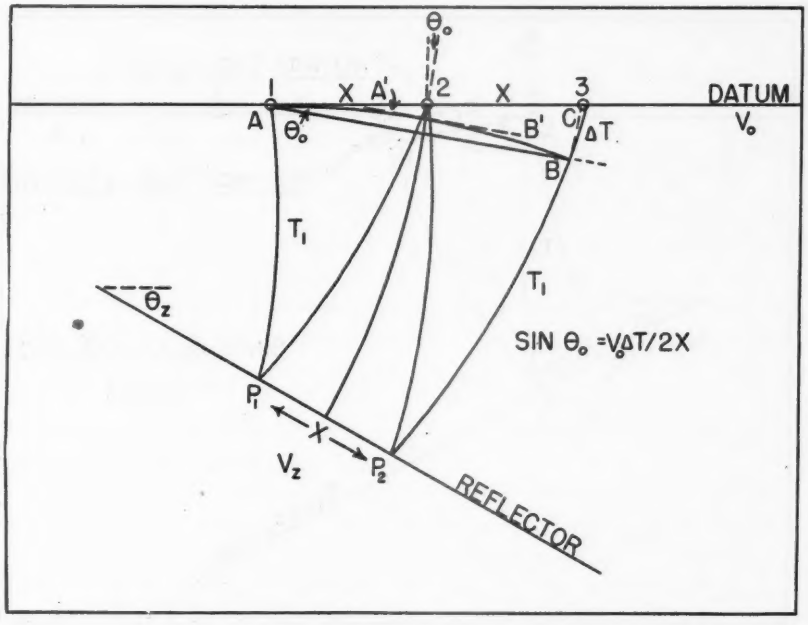

FIG. 4. Diagram for calculation of dip for split spreads.

is the time from Shot-Point 2 to a geophone at Shot-Point 1. Still neglecting the curvature of the emergent ray over the short distance BC, we may also replace wave-front arc AB by the chord AB, which has practically the same dip as the tangent to the arc, $A'B'$. Since this tangent is perpendicular to the ray emerging near Shot-Point 2, it dips at an angle θ_0 from the horizontal, and line AB also has the same dip θ_0 which it is desired to evaluate.

From triangle ABC we then have:

$$\sin \theta_0 = BC/AC = V_0\Delta T/2X, \qquad (10\text{-a})$$

which is the same formula for the same coverage as in the shot-point

to shot-point calculation. The time ΔT is here already a one-way time, and the 2 comes into the formula from the length of surface coverage, $2X$. By similar triangles in Figures 3 and 4, it may also be observed that the one-way time, ΔT, in Figure 4 is the same as the two-way time, ΔT, in Figure 3, so that regardless of spread type, the same subsurface coverage gives the same time difference for purposes of dip calculation.

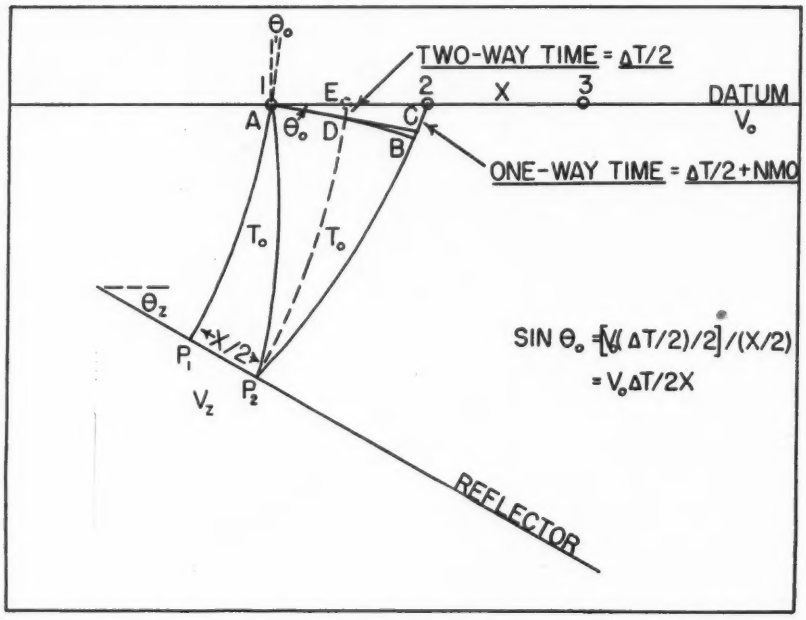

FIG. 5. Diagram for calculation of dip for single-end spreads.

The third type of field set-up, the single-end spread, is illustrated in Figure 5. This shows a spread in the same vertical section as before with the same surface coverage, X, between Shot-Point 1 and Shot-Point 2, but this time only shot from the former point, and including the subsurface coverage of length close to $X/2$ between the reflection points P_1 and P_2. The arrangement is similar to one side of the previous split spread, and by analogy to that case, the line AB dips at an angle θ_0.

Since the arrival time for the end geophone near Shot-Point 2 depends partly on the dip and partly on the normal move-out for the spread length X (discussed below), we first apply a normal move-out

correction to said arrival time, and get the equivalent of the two-way time between an hypothetical shot point midway between 1 and 2, and the reflection-point P_2, this time being along a ray path similar to the one from Shot-Point 1 to P_1. The time difference for two-way time along these ray paths is half that observed in the case of the set-up in Figure 3, and we thus here define θ_0 by the relation:

$$\sin \theta_0 = DE/(X/2) = V_0(\Delta T/2)/2(X/2),$$

or

$$\sin \theta_0 = V_0 \Delta T/2X, \qquad \text{(10-b)}$$

which again contains a 2 in the denominator in view of the two-way time at the hypothetical Shot-Point 1-½.

It is apparent from the above that regardless of the type of field data, we can use equation (8) to calculate dip if we first define θ_0 through the use of equation (10) and a proper selection of subsurface coverage and time difference, reducing the coverage to a standard length if necessary by the use of a reduction factor.

Returning again to equation (8), we may now discuss its application to a slide rule. If we take its logarithm to the base e, we have:

$$\ln \tan (\theta_s/2) = \ln \tan (\theta_0/2) + aT_0/2. \qquad \text{(11)}$$

To perform this addition mechanically on a slide rule, we proceed with the following steps (see Figs. 6 and 7):

(1) Construct a set of T_0 scales, proportional in length to $(aT_0/2)$, and graduated in terms of T_0 (seconds of time). In the case of the new circular form of rule, we replace a single such scale by a chart of T_0 lines for the whole range of a values between 0 and 1.6, readable in steps of 0.01. By setting an index rider under the proper a value and reading the chart along it like a single scale for this a value, the effect with respect to the rest of the slide rule is the same as if only this T_0 scale were combined with the other parts of a 10-inch slide rule near the edge of the disc.

(2) Construct a ΔT scale proportional in length to $\ln \tan (\theta_0/2)$, and graduated in terms of $\sin \theta_0$. The proportionality factor is open to choice, so using equation (10), we have in the present case selected a ratio of datum velocity to subsurface coverage such that $V_0/2X = 10$ sec^{-1}. With this ratio, the graduation of the scale in terms of $\sin\theta_0$ is numerically equivalent to a graduation in thousandths of a second of observed ΔT due to dip for a subsurface coverage which is 1/10 of the datum velocity in English or metric systems, as the case may be.

(3) Construct a dip scale proportional in length to ln tan $(\theta_z/2)$, and graduated in terms of θ_z or tan θ_z, as desired. The present slide rule is calibrated in degrees only (see Figs. 6 and 7), but could as well show dip tangents.

With the above scales mounted in their proper relationship, most

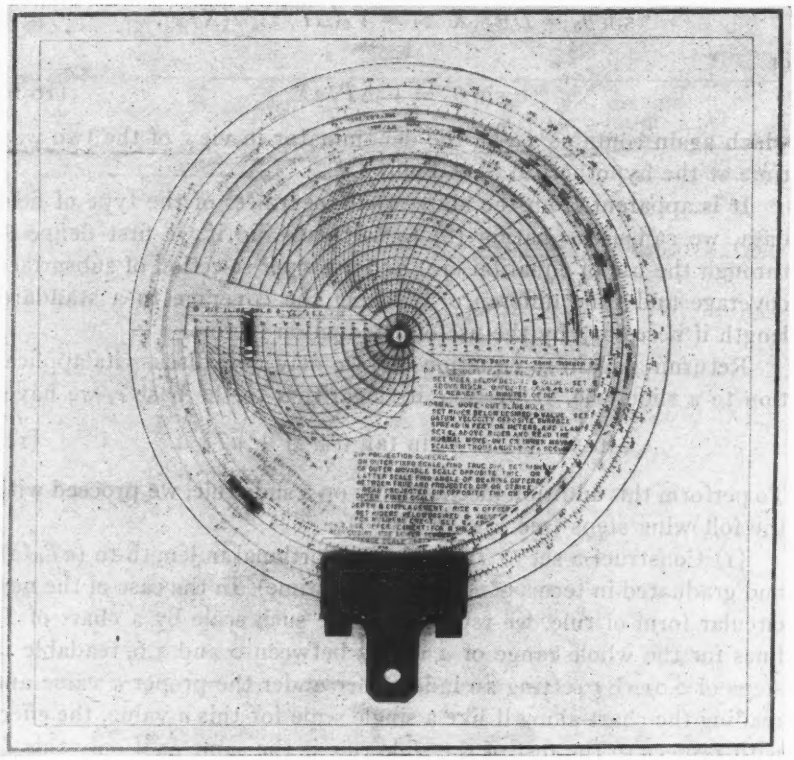

FIG. 6. Circular slide rule, assembled. Front view: dip, normal move-out, and dip projection.

readily found by setting up a simple numerical problem, we have in the present slide rule the equivalent of a 10-inch slide rule applicable to any desired V_0 ordinarily met, any a value between 0 and 1.6, readable in steps of 0.01, and any T_0 up to 6 seconds. We can read the dip or its tangent for dips from 0° through 90°, to overturned dips of 55°. This is a generalized form of a straight slide rule devised by R. A. Peterson, which had single removable scales for various a values and

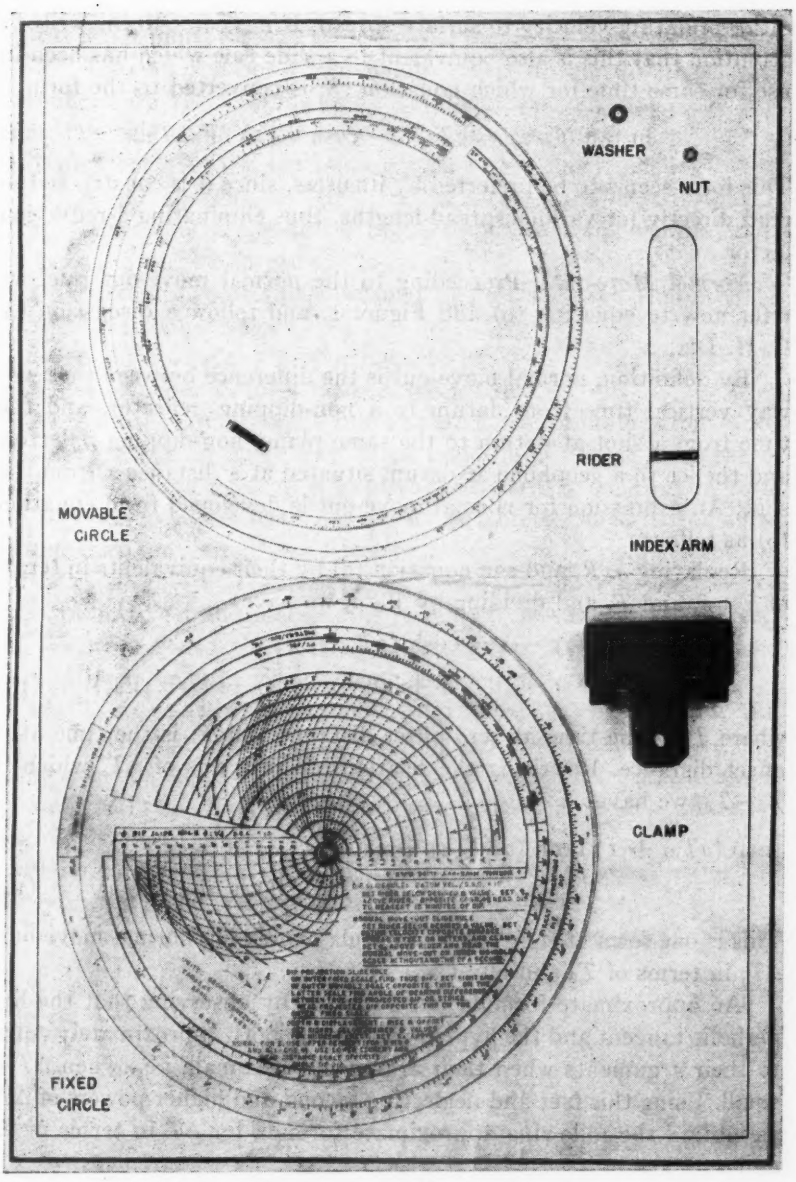

FIG. 7. Circular slide rule, unassembled. Front view: dip, normal move-out, and dip projection.

ratios of datum velocity to surface spread. It has come to the writer's attention that this is also equivalent to a slide rule which has been in use for some time for which equation (8) is converted to the form:

$$\ln \tan (\theta_s/2) = aT_0/2 - \cosh^{-1} (2X/V_0\Delta T). \qquad (12)$$

This form seems to be preferred by its users, since it is constructed to read directly for various spread lengths, thus eliminating a reduction factor.

Normal Move-out.—Proceeding to the normal move-out rule, we refer now to equation (9) and Figure 2, and follow a discussion by C. H. Dix.

By definition, normal move-out is the difference between the two-way vertical time from datum to a non-dipping reflector, and the time from a shot at datum to the same plane, non-dipping reflector, and thence to a geophone at datum situated at a distance x from the shot. An expression for normal move-out is developed from equation (9) as follows:

Replacing h, R, and z in equation (9) by their equivalents in terms of V_0, a, and T. and dividing by V_0/a, we have:

$$\exp (aT_0/2) - 1 = \cosh (aT_x/2) - 1 + [\sinh^2 (aT_x/2) - a^2x^2/4V_0^2]^{1/2}, \qquad (13)$$

where T_0 is the time at zero offset distance and T_x is the time at x offset distance. Rewriting the relationship in terms of ΔT, which is $T_x - T_0$, we have:

$$[\exp (aT_0) + 1] \tanh (a\Delta T/4) + \exp (aT_0) - 1 = [a^2x^2/4V_0^2](1/\sinh a\Delta T/2). \qquad (14)$$

This is one form of the "exact" formula expressing normal move-out, ΔT, in terms of T_0 and offset x.

An approximate formula can be found by observing that the hyperbolic tangent and the hyperbolic sine are both approximately equal to their arguments when their arguments are small, i.e., when ΔT is small. Using this fact and neglecting second and higher powers of ΔT, we obtain the following approximate formula for ΔT in terms of T_0 and x:

$$\Delta T = [a\, x^2/2V_0^2](1/\exp (aT_0) - 1). \qquad (15)$$

Taking the logarithm of this, we have

$$\log \Delta T = \log (ax^2) - \log 2V_0^2 - \log (\exp (aT_0) - 1). \qquad (16)$$

This is the formula on which the normal move-out slide rule is based, subject to modifications noted below which correct for inaccuracy introduced by the assumptions mentioned regarding ΔT. The first such slide rule was devised by J. A. Legge.

Using formula (16), the following scales are constructed:

(1) A scale proportional to log ΔT and calibrated in terms of ΔT.

(2) A scale or scales proportional to log ax^2, and calibrated in terms of the surface spread x.

(3) A scale or scales proportional to log $2V_0^2$, and calibrated in terms of the datum velocity V_0.

(4) A scale or scales proportional to log (exp $(aT_0)-1$) and calibrated in terms of T_0 for some selected a value.

The present circular slide rule has a ΔT scale running from 0.001 to 0.100 seconds, it being considered undesirable to use this type of correction for larger values. It has two spread scales, one running from 300 to 3,000 feet, and one from 90 to 900 meters, the scales being so related that conversions from feet to meters can be read from them for the range covered. Corresponding to the spread scales are velocity scales in both feet and meters, one running from 5,000 to 15,000 feet, and the other from 1,500 meters to 4,500 meters. These scales can also be used for interconversion between feet and meters.

The T_0 scale, as in the case of the dip slide rule, is arranged in the form of a chart of T_0 lines for the range of a values from 0 to 1.4, readable in steps of 0.01. Using an index rider, the chart is read along the rider as if the T_0 scale selected were part of a 10-inch slide rule near the edge of the disc.

As noted above, the slide rule can be modified to give greater accuracy in the higher values of ΔT.

For this purpose, equation (13) may be converted into the form

$$\coth p(\cosh q - 1) + \sinh q = r_0, \tag{17}$$

where

$$p = aT_0/2, \qquad q = a\Delta T/2, \qquad r_0 = a(\Delta T)_0/2$$

where $(\Delta T)_0$ is the approximate ΔT found on the normal move-out slide rule using equation (15).

Curves plotted from equation (17) will give the exact ΔT corresponding to the various approximate ones on the slide rule as shown. An investigation of these exact values indicates that the slide rule can be modified to give a second approximation of accuracy by adding a

chart of exact-value lines corresponding to various values of initial velocity and spread. This chart is read along a spiral index line controlled by the initial velocity to spread ratio. It turns out that this series of exact values is not sensitive to changes in a value, so that the

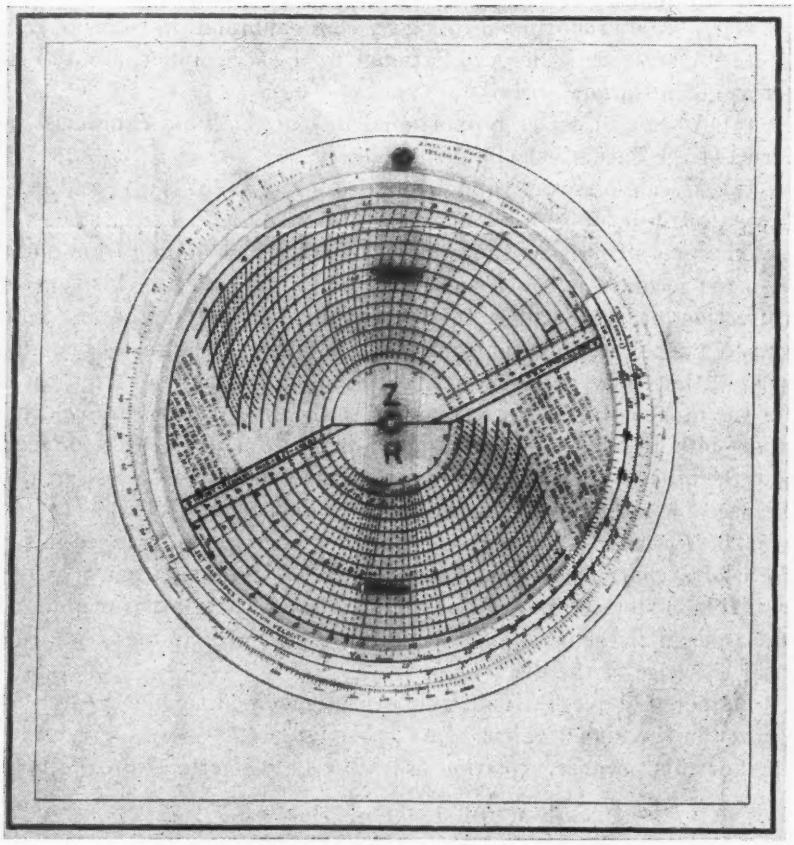

FIG. 8. Circular slide rule, assembled. Rear view: depth and displacement, rise and offset.

calibration is readily done using a simple straight-line calculation formula where $a=0$. This second approximation brings the slide rule readings into amply accurate range for values of ΔT under 0.100 second.

Depth and Displacement.—The combined depth and displacement

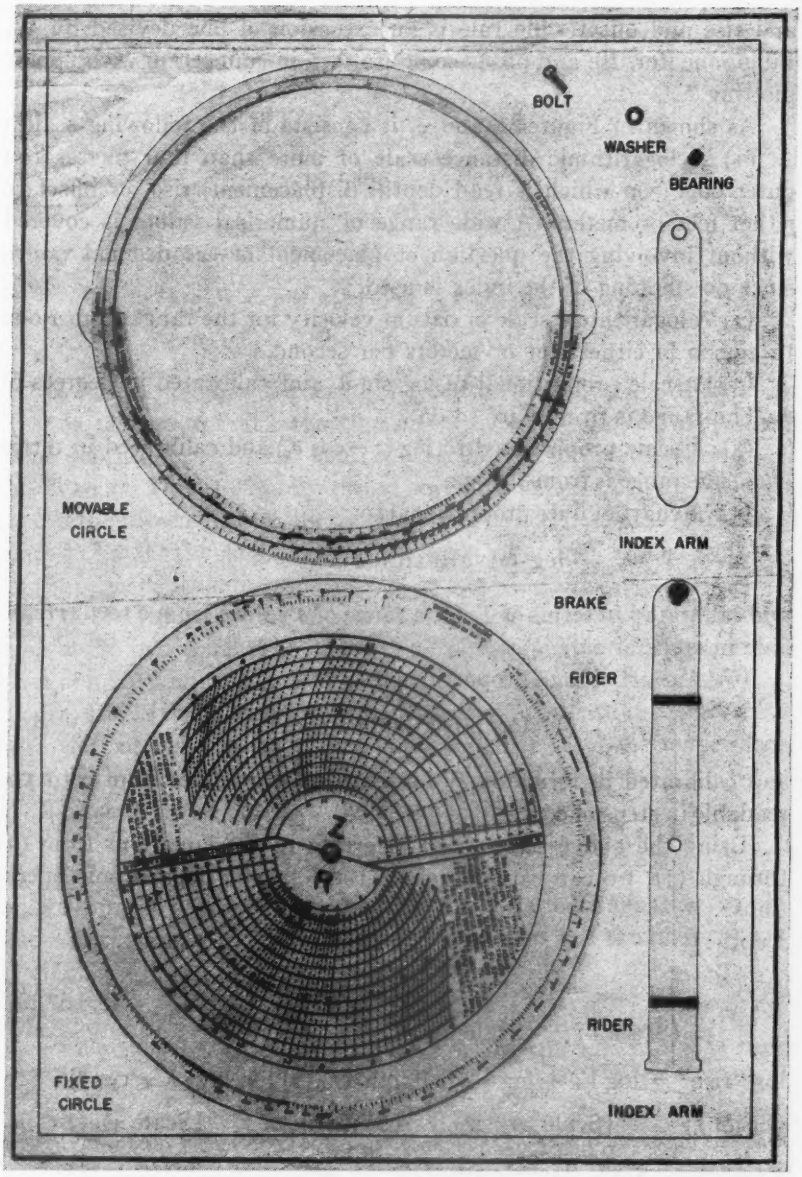

FIG. 9. Circular slide rule, unassembled. Rear view: depth and displacement, rise and offset.

and rise and offset slide rule is an extension of one devised by W. Fillippone[4] for rise and offset computations in connection with "point plotting."

As shown in Figures 8 and 9, it consists of the following scales:

(1) A logarithmic distance scale of more than four phases (on outer edge) on which is read depth, displacement, rise, or offset in either feet or meters. A wide range of numerical values is covered without involving the question of placement of the decimal point, since no stepping of the index is used.

(2) A logarithmic scale of datum velocity for the range from 1,000 to 20,000 in either feet or meters per second.

(3) A scale proportional to log sin θ_z and calibrated in degrees of θ_z. The range is from 0°40′ to 90°.

(4) A scale proportional to log $(1-\cos\theta_z)$ and calibrated in terms of θ_z. The range is from 1° to 90°.

(5) A chart of lines proportional to

$$\log\left[(1/a)(\exp(aT_0/2)-1)\right]$$

and calibrated in terms of T_0 for a range of a values from 0 to 1.4, readable in steps of 0.01.

(6) A chart of lines proportional to

$$\log\left[(1/a)(\sinh aT_0/2)\right]$$

and calibrated in terms of T_0 for a range of a values from 0 to 1.4, readable in steps of 0.01.

Using the above scales, and referring to the equations from (3) through (7), we can carry through the following logarithmic operations:

Depth:

$$\log z_{\max} = \log V_0 + \log\left[(1/a)(\exp(aT_0/2)-1)\right]. \qquad (18)$$

(Scale 1) (Scale 2) (Scale 5)

$$\log \text{"rise"} = \log V_0 + \log\left[(1/a)(\sinh aT_0/2)\right] + \log(1-\cos\theta). \qquad (19)$$

(Scale 1) (Scale 2) (Scale 6) (Scale 4)

From these, for a dipping reflector,

$$z = z_{\max} - \text{"rise."} \qquad (20)$$

[4] W. R. Fillippone, GEOPHYSICS, XI, 92–95, No. 1 (January, 1946).

Offset (=displacement):

$$\log \text{"offset"} = \log V_0 + \log\left[(1/a)(\sinh aT_0/2)\right] + \log \sin\theta. \qquad (21)$$

(Scale 1) (Scale 2) (Scale 6) (Scale 3)

h, R, and z:

$$h = z_{\max} - R, \qquad (22)$$

where $z_{\max}$ is found as above, and

$$\log R = \log V_0 + \log\left[(1/a)(\sinh aT_0/2)\right]. \qquad (23)$$

(Scale 1) (Scale 2) (Scale 6)

It is also possible to operate the depth determination of equation (18) in reverse to find a function of the type $V = V_0 + az$ to fit given time-depth data from any source, especially from the seismic surveys of oil wells. This is done by trying several a values until an optimum one is found which, with its constant V_0 setting, best fits the range of data in hand. The lack of fit at any point, of course, is then available in the same depth unit, whether feet or meters.

Dip Projection.—The dip-projection slide rule allows the calculation of dip in a vertical plane oriented a given number of degrees from that of a known true dip. The slide rule was originally devised by J. A. Legge, and in its present form the main modification is the elimination of a shift of index at 45°, since in the circular form the longer scale occupies more than 20 inches of the perimeter of the disc.

The slide rule is based on the formula:

$$\tan\phi = \tan\theta \cos\alpha, \qquad (24)$$

where ϕ is the desired dip in the plane of projection, θ is the true dip, and α is the angle between the plane of true dip and the plane of projection.

Adapting equation (24) for slide rule use,

$$\log \tan\phi = \log \tan\theta + \log \cos\alpha, \qquad (25)$$

(Scale 1) (Scale 1) (Scale 2)

where only two scales are required:

(1) a scale proportional to log tan ϕ (or log tan θ) and calibrated in terms of degrees of ϕ (or θ),

(2) a scale proportional to log cos α, and calibrated in terms of degrees to α.

This slide rule gives the same results as may be obtained from a chart by W. S. Tangier-Smith, which is reproduced in Appendix XIV of Lahee's "Field Geology" (McGraw-Hill, 1941), and is easier to read than the chart.

Construction and Operation.—The construction of the circular slide rule is still in a somewhat experimental stage, especially as regards ranges of variables, interval divisions, etc. It is based on the wrapping of two 10-inch slide rules around a circle of radius near $3\frac{1}{2}$ inches. All other circles on the slide rule are graduated using radial projections inward or outward, from the base circle.

Most of the readings are comparable to those obtainable from a straight 10-inch slide rule, which in general means that accuracy is adequate for dip, normal move-out, and dip-projection computations, since with these no greater accuracy is warranted by original data. For depth and displacement, etc., the accuracy is sufficient for mapping most dip data but not for work on large vertical sections. For these it is preferable to work from charts, though a large-model slide rule accurate to four places or better might be made.

For manufacture, a photographic negative is used for contact prints of suitable size, which are then cut and lacquered to the under sides of plastic discs, and assembled using numerical checks of the answers to adjust for any error due to shrinkage of the prints.

For the depth and displacement rule, it is usually desirable to hold the same datum-velocity setting for a series of operations, so a brake device is provided on the far end of the index bar, bearing on the edge of the movable plastic disc. Stops prevent the brake from moving around the disc to damage the scale on the other side. Also, riders are provided on index arms for each a scale, and friction holds these in place for a series of operations. And, finally, a clamp with dulled edges is provided to hold the spread and datum-velocity setting fixed for normal move-out readings for a series of times.

A list of operating instructions is printed on the slide rule, and a similar list is given below for reference.

INSTRUCTIONS

(1) *Dip Slide Rule.*—(Datum Velocity/Subsurface Coverage = 10)
Set rider below desired a value. Set T_0 above rider. Opposite corrected ΔT read dip to nearest 15 minutes of dip.

(2) *Normal Move-out Slide Rule.*—Set rider below desired a value. Set datum velocity opposite surface spread in feet or meters, and

clamp. Set T_0 above rider and read the normal move-out on inner movable scale in thousandths of a second.

(3) *Dip-Projection Slide Rule.*—On outer fixed scale find true dip. Set right end of outer movable scale opposite this. On the latter scale find angle of bearing difference between true and projected dip or strike. Read projected dip opposite this on outer fixed scale.

(4) *Depth and Displacement* and *Rise and Offset.*—Set riders below desired a values for numbers erect. Set T_0 above rider. For z, use upper segment; for $R \sin \theta$ and $R(1-\cos \theta)$ use lower segment and read distance scale opposite angle of dip.

$$\text{Depth} = z_{max} - R(1 - \cos \theta),$$
$$\text{Displacement} = \text{Offset} = R \sin \theta,$$
$$\text{Rise} = R(1 - \cos \theta).$$

(5) To fit a function $V = V_0 + az$ to known time-depth data, use trial a value with a known time and depth to get trial V_0. When using this same V_0 and same a, use other known times to compute corresponding depths to compare with the given depths. When the agreement is satisfactory, the trial values define the function.

(6) To fit a function $V = V_0 + az$ to known time and ΔT data, use trial a values on the normal move-out rule to find optimum fit, reading V_0 opposite the spread length used.

CONCLUSION

Since the work of many people is combined in the development of the circular slide rule, it should be noted again that the principal new feature is the spreading of the time scales into charts covering a wide range of functions. Other new features are the inclusion of overturned dips, the presentation of the dip-projection rule without a break at 45°, and the extension of the rise and offset rule to include total depth. The calibration for both feet and meters, and the reverse use of the depth and normal move-out rules to fit functions to given data also are new.

The theoretical basis for the rule is mainly due to the persons listed in the references, and the writer is particularly indebted to C. H. Dix and R. A. Peterson for much of the theoretical outline and to the United Geophysical Company for permission to release this paper.

A SHOOTING METHOD FOR AREAS OF DIFFICULT DRILLING*

E. D. ALCOCK† AND K. H. WATERS†

ABSTRACT

This paper describes an economical method for shooting in areas where shot-hole drilling is expensive. A new computational procedure for handling the data in steep-dip areas is derived.

INTRODUCTION

In many areas of difficult surface drilling, the cost of performing even a reconnaissance reflection seismic survey increases far beyond what is normally expected. The cost can, to some extent, be reduced by increasing the number of drills until the recording crew is fully employed, but even this means a greater than average cost for the area.

The method described in this paper has been used in an area where the drilling conditions are, in some parts, as difficult as any to be encountered in this country. This method shows how one hole can be used a large number of times to give information which would normally have been obtained by other holes. This is a variant of the continuous-profile method of shooting, using a much greater distance between shot points than is normal.

In areas of gentle dips the routine computational procedure gives reasonably accurate results. In areas of steep dips, however, the routine computational procedure is highly inaccurate, and it was necessary to derive a new procedure to make full use of the data obtained.

FIELD PROCEDURE

In Figure 1 is shown a plan of the field arrangement used. It consists of a number of linear seismometer spreads laid end to end, with the end spread of the line in each case being laid symmetrically across the shot hole. The number of spreads between the shot holes is variable and depends to a large extent on the continuity of the reflecting horizons. However an upper limit is set to the distance between shot holes by the fact that, as the distance is increased, the refractions

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† National Geophysical Co. Inc.

from the near surface beds tend to hide the shallow reflections. In practice, it is inadvisable to extend the distance between shot holes beyond 10,000 feet.

Across the two holes and at right angles to the longitudinal spreads are two cross spreads. These spreads need not be the same lengths as

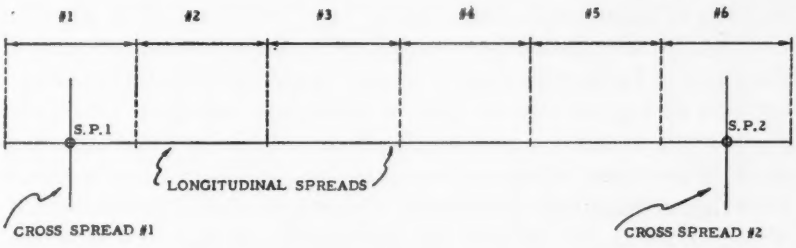

FIG. 1. Plan of field arrangement used.

the longitudinal spreads (if topographic difficulties prevent it), but they should at least be symmetrical with respect to the shot hole.

Shooting procedure is as follows:

A. The longitudinal spreads are shot, in turn, from each of the two holes. It may be of some advantage, from the point of view of time-saving, to employ two shooting trucks equipped for radio communication with the recording truck.

B. The cross spreads are shot, both from the hole across which they lie and also from the opposite hole; e.g., Cross Spread No. 1 is shot from both holes 1 and 2.

C. In areas where weathering changes are significant, shallow weathering shots should be taken at each spread.

The order of shooting is immaterial. However, in order to speed the work, the fact that some of the spreads are common to several holes should be borne in mind. For example, in the course of shooting a continuous line by this method, the cross spreads have to be shot three times, each time from a different hole. This also applies to the longitudinal spreads across the holes. All other spreads are shot from two different holes.

The exact shooting order for maximum economy of time will depend on the number of shooting or recording units available and also on the number of traces available in the recording unit.

INTERPRETATION PROCEDURE

It is advisable to consider the longitudinal spreads first since, by their use, some idea may be gained of the continuity of the reflections. Starting from SP 1, reflections which appear on the longitudinal spread No. 1 are traced from it to longitudinal spread No. 2, and by time ties as far as longitudinal spread No. 6, which straddles hole No. 2. Thus the six spreads are treated as a single continuous spread. Then just as for normal continuous-line work, the reflection is identified by a time tie on the end trace of the records shot from SP 2. (The time on the center trace longitudinal spread No. 1 shot from SP 2 must be the same—after surface corrections are made—as the center trace time of longitudinal spread No. 6 shot from SP 1.) The reflection is then traced back across the several records until its zero-trace time at SP 2 is obtained. This procedure is carried out for all reflections which have continuity throughout the records.

Thus far, the procedure has been similar to that of any continuous-profiling method. Provided that the strata underlying the area are relatively flat, computations may then be made to determine the depths below the shot points, and by assuming that the velocity function is correct and by using the conception of "normal moveout," depths may be computed for any of the points between the two shot points.

Any error in the velocity function will be discovered very rapidly by reference to the cross sections. An error in the velocity function will produce a serrated effect in the cross section; that is, the depths determined for mid-points between the shot points will not approximate the average of the depths computed for the points directly below the shot points. This is a well known effect and needs no further description; suffice it to say that by adjusting the velocity function until the cross section becomes smooth, one can obtain a reasonably accurate function.

Two sets of records for the type of shooting under consideration are reproduced as Figures 2*a* and 2*b*. These records were not taken in the steeply dipping portion of the area, but the steep dip encountered is well illustrated by the records which appear as Figure 3.

Up to the present it has been assumed that the subsurface dips are small. This profiling method, however, by making use of the extra measurements which have hitherto not been used, can be equally well applied to steeply dipping strata provided that reflections having sufficient continuity are obtained. In the area for which the method

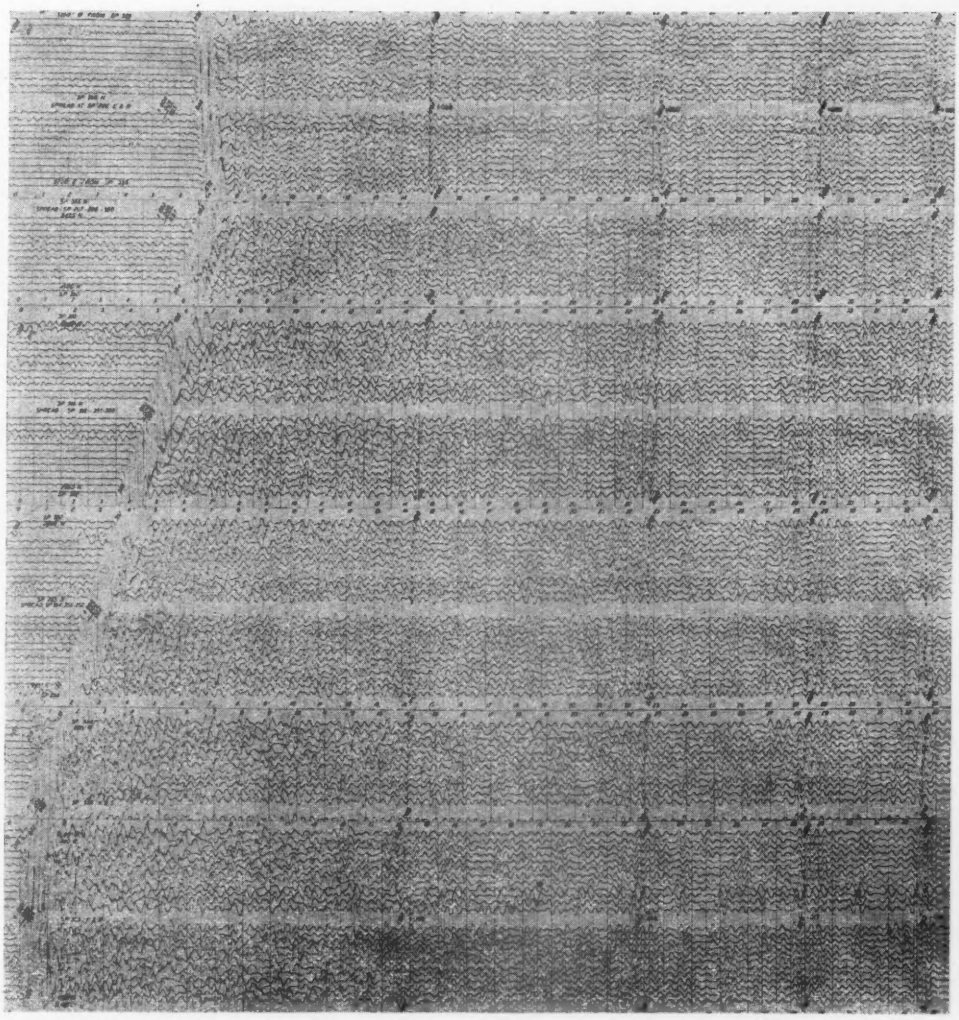

FIG. 2a. Example of records for this type of shooting.

was developed, both steep and flat dips occurred. It therefore became necessary to devise a means of obtaining from the records the necessary structural information for the steep-dip portions also.

First of all, it is obvious that, with steeply dipping strata, three-dimensional control over the position of the reflecting point (for normal perpendicular reflection) for each shot point is needed. This, of course,

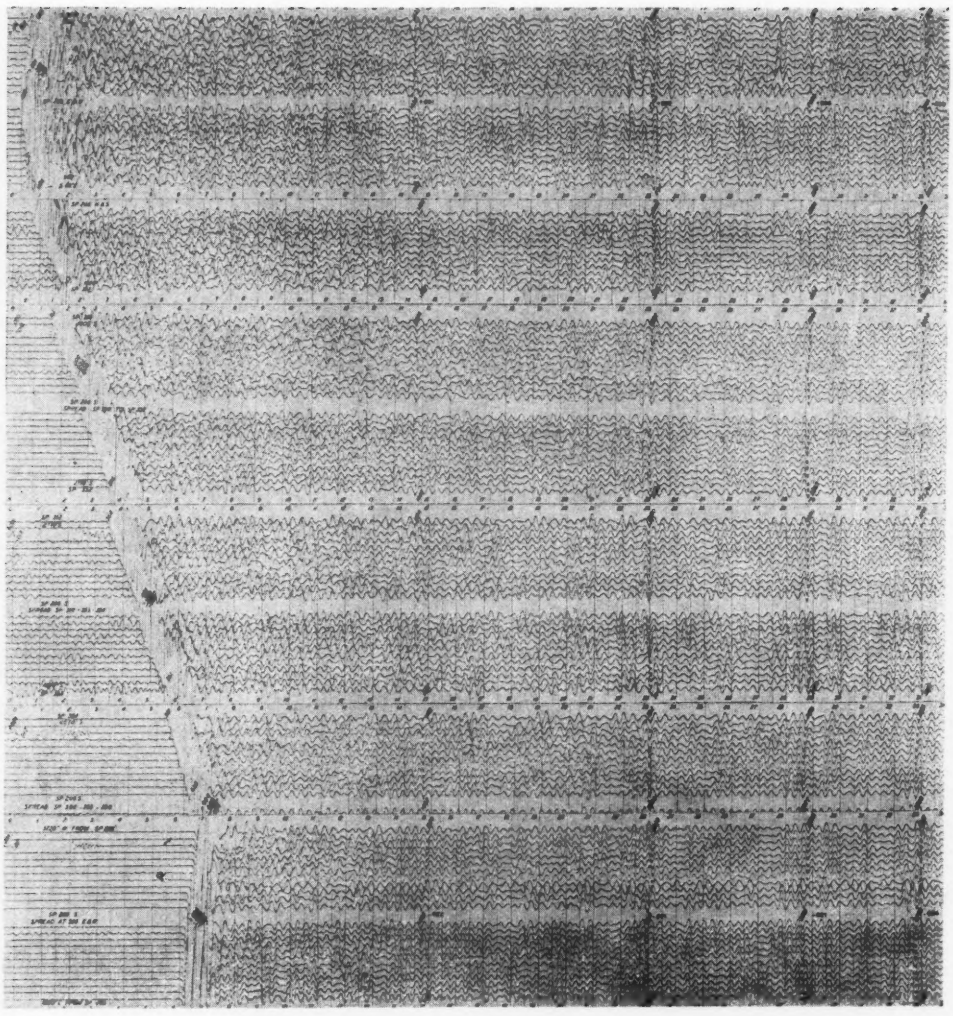

FIG. 2b. Example of records for this type of shooting.

means that a supplementary dip measurement at right angles to the line between the shot points must be made. These supplementary dip measurements result from the shooting of the cross spreads Nos. 1 and 2 from SP's 1 and 2, respectively.

A previous paper by one of the authors[1] has shown how two dip

[1] Kenneth H. Waters, *A Numerical Method of Computing Dip Data Using Well Velocity Information*, GEOPHYSICS, VI, No. 1 (January, 1941).

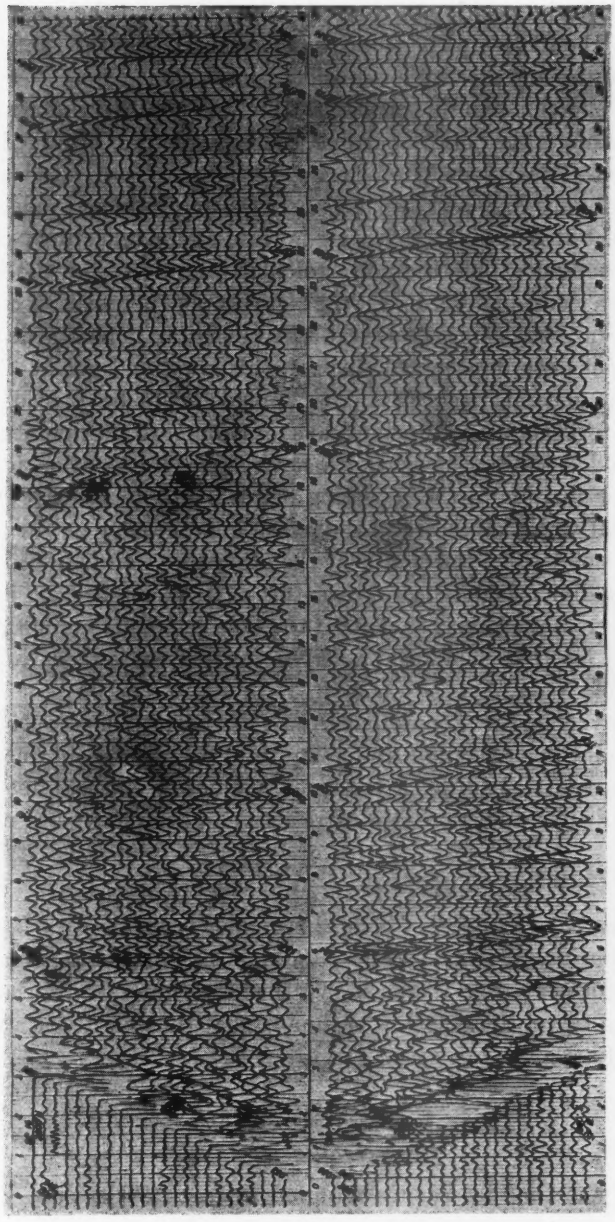

FIG. 3. Record indicating steep dip.

measurements at right angles may be computed using a curved-path method to give the position of the reflecting point and the angle and azimuth of the true dip. This method was used for the steep-dip computations for the area under consideration.

Since a reflection can be correlated from one point to the next by the time ties along the continuous line, the two true dips obtained can be correlated. Thus, instead of having two depths correlated as in normal continuous-line work, we have here the depths of two reflecting points and the strikes of the reflecting horizon at the reflecting points.

So far, moreover, only the perpendicular reflection from the horizon has been considered, and the law governing the position of the reflecting point between its two established positions beneath the shot points has not been determined. In fact, this law could not be determined in the general case unless cross spreads could be placed infinitely close together along the line and shot from both shot points.

It seemed desirable, however, to have some information for an intermediate position of the reflecting point. The intermediate point chosen is that which gives rise to the reflection appearing on the trace at one shot point when the shot is at the other shot point. In order to obtain three-dimensional control over this particular reflecting point, each of the cross spreads is shot from the hole remote from it; that is cross spread No. 1 is shot from hole No. 2 and cross spread No. 2 is shot from hole No. 1.

It is proved in the Theoretical Analysis that the position of the reflecting point and the angle and azimuth of dip can be obtained for the oblique reflection in much the same manner as it is obtained for the perpendicular reflection. No extra curved-path charts are necessary.

Theoretical analysis

Mathematical derivation of oblique reflection formulae used in computing the position of the reflecting point and the angle and azimuth of dip.—In a former paper[2] it was shown that the time taken for a seismic wave to travel to a depth z, assuming that the velocity is a function of z only, is given by

$$T = \int_0^z [1/(V_z \cos \theta_z)]dz \qquad (1)$$

where T is the time in seconds required to reach a depth z, V_z the

[2] *Op. cit.*

interval velocity at a depth z, and θ_z the inclination to the vertical of the normal to the wave front at a depth z. Since, by Snell's law

$$\sin \theta_z / \sin \theta_0 = V_z / V_0,$$

where θ_0 is the angle of inclination of the ray at the surface, and V_0 the velocity at the surface, Equation (1) becomes

$$T = \int_0^z \frac{dz}{V_z[1 - (V_z \sin \theta_0 / V_0)^2]^{1/2}}. \tag{2}$$

Now, the moveout ΔT obtained on a surface spread of length x is due to the arrival of the wave at an angle θ_0 and the relation $\sin \theta_0 = V_0 \Delta T / x$ is true. Replacing $\sin \theta_0$ in (2) we have

$$T = \int_0^z \frac{dz}{V_z[1 - (V_z \Delta T / x)^2]^{1/2}}. \tag{3}$$

For a normal reflection perpendicular to the reflecting horizon the wave must travel back along the same path; hence the time of reflection

$$T_r = 2 \int_0^z \frac{dz}{V_z[1 - (V_z \Delta T / x)^2]^{1/2}}. \tag{4}$$

By the use of curves drawn for various values of $\Delta T/x$, this integral equation is solved for z by finding, on the curve having the appropriate parameter $\Delta T/x$, the value of z corresponding to the time T_r.

The same method cannot, however, be applied when the return path is not the same as the downward path. In Figure 4 a diagrammatic sketch shows the conditions when the shot point and the receiving point are not coincident.

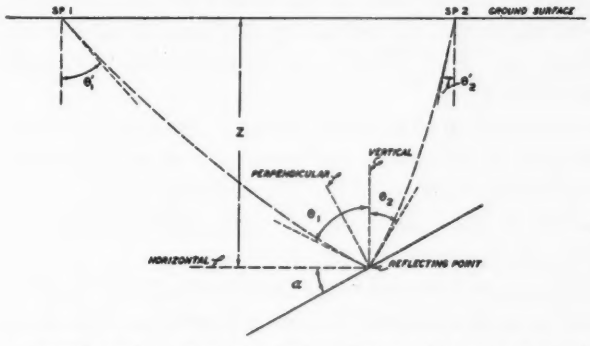

FIG. 4. Condition when shot point and receiving point are not coincident.

For this case it can easily be seen that the total time for reflection will be the sum of the two individual times for the upward and downward paths, or that

$$T_{r_0} = \int_0^z [1/(V_z \cos \theta_{1z})]dz + \int_0^z [1/(V_z \cos \theta_{2z})]dz, \qquad (5)$$

where T_{r_0} is time for an oblique reflection, θ_{1z} the inclination to the vertical of the normal to the wave front which travels downward from SP 1 to the reflecting interface, and θ_{2z} the inclination to the vertical of the normal to the wave front which travels upward from the reflecting interface to SP 2. In a manner similar to that adopted previously this equation can be transformed to

$$T_{r_0} = \int_0^z \frac{dz}{V_z[1 - (V_z \Delta T_1/x)^2]^{1/2}} + \int_0^z \frac{dz}{V_z[1 - (V_z \Delta T_2/x)^2]^{1/2}}, \qquad (6)$$

where ΔT_1 and ΔT_2 are the moveouts obtained on spreads of length x, the spreads being arranged symmetrically over SP's 1 and 2, and with the shots at SP's 2 and 1, respectively. On the T-z chart having curves for various values of the parameter $\Delta T/x$ it is possible to pick out one curve having a parameter $\Delta T_1/x$ and another having a parameter $\Delta T_2/x$. By following these curves downwards until their individual values of T (at the same value of z) add up to T_{r_0}, the correct depth z is obtained. It is fairly obvious that this is just a generalization of the procedure for normal reflections. This procedure is, however, somewhat tedious and it has been found beneficial to make up two T-z charts, printed in such a way that one is a mirror image (about the z-axis) of the other. These two are then joined along the z-axis as shown in Figure 5.

It is now possible to construct a scale, graduated in time units (to the same scale as is used in the charts), and to arrange it so that it may be moved up and down the T-z chart in such a way as to be always parallel to the time scale. (A mechanical drafting machine is a useful adjunct to accomplish this.)

This time scale is now moved downwards, keeping the zero on the curve having a parameter of $\Delta T_1/x$, appearing on the left-hand chart. The curve having a parameter $\Delta T_2/x$ is then selected on the right-

hand chart and the horizontal scale is moved downwards until the $\Delta T_2/x$-curve intersects the horizontal scale at the required time T_{r_0}. The required depth z is then read on the z-scale. Although this procedure appears to be complicated, a good deal of dexterity can be acquired with a little practice, and very rapid depth determinations

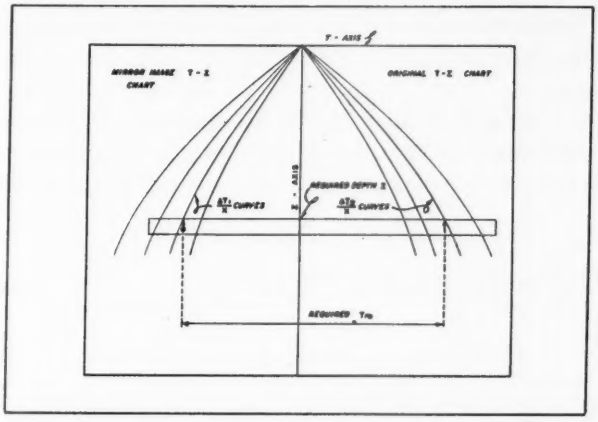

FIG. 5. Compound T-z chart symmetrical about z-axis.

can be made. Once the depth z of the reflecting point has been determined, it is easy to establish the other coordinates.

Figure 6 shows a plan view of the two shot points and the cross

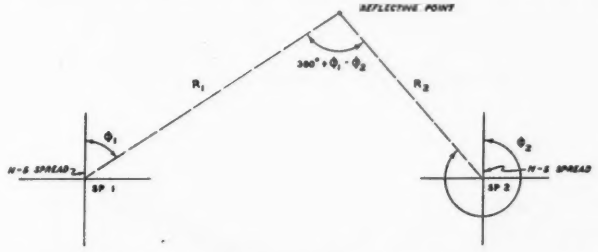

FIG. 6. Plan view showing two shot points with cross spreads and horizontal projections of the reflecting point.

spreads at these points, as well as the horizontal projection of the reflecting point.

It was proved in a previous paper[3] that the horizontal displace-

[3] *Op. cit.*

ment R of a point on the ray after it had traveled to a depth z is given by

$$R = \int_0^z \tan \theta dz = \int_0^z \frac{\Delta T/x}{[1/V_z^2 - (\Delta T/x)^2]^{1/2}} dz. \tag{7}$$

A standard set of curves is prepared for various values of the parameter $\Delta T/x$. These curves have already been drawn for the computation of normal reflections and can be used without alteration for the oblique computations.

From the moveouts which are observed on the records for the N-S and E-W directions at SP 1, when shot from SP 2, the azimuth ϕ, of the reflecting point is obtained (if the spread lengths are equal),

$$(\Delta T_{NS}/\Delta T_{EW})_{SP1} = \cot \phi_1.$$

Similarly the angle ϕ_2 can be found.
Also

$$(\Delta T_{NS}/x)_1^2 + (\Delta T_{EW}/x)_1^2 = (\Delta T_1/x)^2.$$

Select the curve on the R-z chart having the correct parameter $\Delta T_1/x$ and read off the horizontal displacement (R_1) corresponding to the

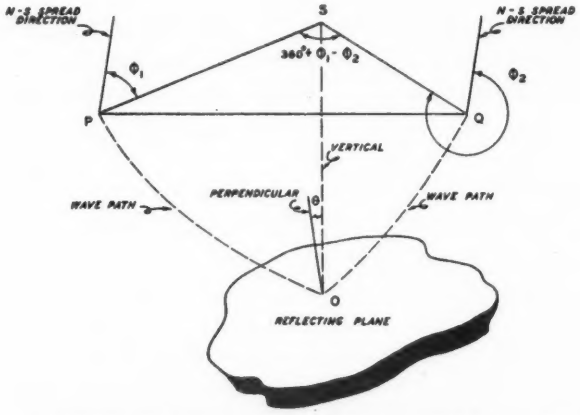

FIG. 7. Diagrammatic representation of three-dimensional conditions.

depth already found (z). In a similar manner R_2 may be obtained from the $(\Delta T_2/x)$-curve.

Now, since one horizontal distance, R_1 or R_2, and one azimuth, ϕ_1 or ϕ_2, are sufficient to specify the horizontal position of the reflecting point, the other pair will serve merely as a check.

Once the coordinates of the reflecting point have been obtained, the remaining unknowns are the angle of true dip and its azimuth. To derive this information further investigation of the geometric conditions at the reflecting point is required.

Figure 7 is a diagrammatic representation of the three-dimensional conditions. This sketch shows the curved paths taken by the rays, and the vertical and the perpendicular at the reflecting point.

Now let us look at the conditions prevailing very near to the reflecting point, close enough to the reflecting point that the rays may be regarded as straight lines. In Figure 8, *ACD* is a horizontal plane drawn at a small vertical distance δz above the reflecting point, at *O*. The plane intersects the two rays at *C* and *D* and the perpendicular to the reflecting surface at *B*.

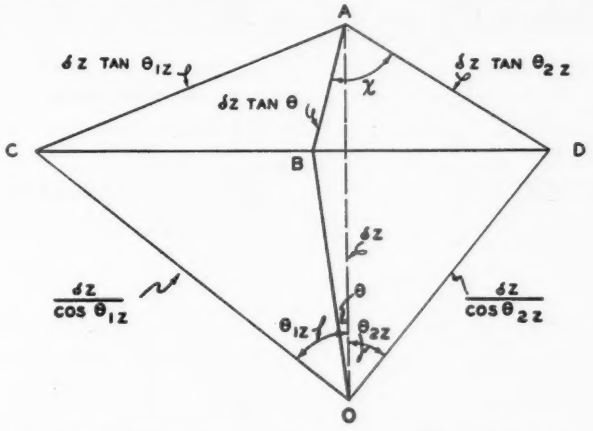

FIG. 8. Conditions prevailing very near the reflecting point.

The angles *AOC* and *AOD* can be determined and are equal to θ_{1z} and θ_{2z}, respectively. The angle *AOB* (angle θ) is the true angle of dip. Furthermore, since *ADO* is in the same plane defined (in Fig. 7) by the curved path, by the vertical, and by the line *SQ*, and similarly *ACO* is in the same plane as *SPO*, the angle *CAD* is equal to the angle *PSQ*, which is equal to $360^\circ+\phi_1-\phi_2$.

The direction of *AB* and the magnitude of θ are required.

One other fact remains. According to the physical laws governing reflection at an interface, the angle *DOB* must equal the angle *BOC* and, moreover, the incident and reflected rays and the normal to the surface must lie in the same plane. Hence, the perpendicular (*OB*) must cut the line *CD*.

Examining now the magnitudes of the sides of the triangles involved (Fig. 8)

$$AD = \delta z \tan \theta_{2z},$$
$$AC = \delta z \tan \theta_{1z},$$
$$AB = \delta z \tan \theta,$$
$$CO = \delta z / \cos \theta_{1z},$$
$$DO = \delta z / \cos \theta_{2z}.$$

Although it is possible from simple geometry to derive a formula for the angle χ and the length AB (and hence, to determine the angle θ), it has been found simpler to solve the problem graphically. This amounts to nothing more than reducing Figure 8 to a plane figure. Refer to Figure 9. The construction of this figure is as follows:

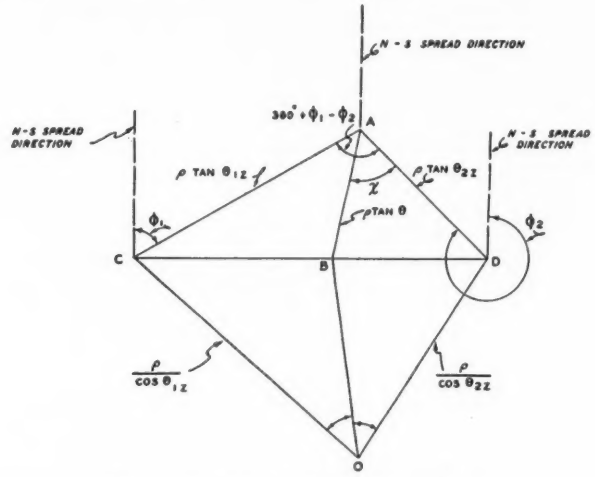

FIG. 9. Graphic solution of the problem.

(a) Compute the angles $\theta_1 z$ and $\theta_2 z$ from the formulae

$$\sin \theta_{1z} = V_z(\Delta T_1/x),$$
$$\sin \theta_{2z} = V_z(\Delta T_2/x).$$

(b) Lay out two lines (AC and AD) of lengths $\rho \tan \theta_{1z}$ and $\rho \tan \theta_{2z}$ at an angle $360° + \phi_1 - \phi_2$. Here ρ is a constant to give a suitable scale to the drawing

(c) Join the two points C and D.

(d) From C and D construct a triangle whose sides are CO and DO equal to $\rho/\cos\theta_{1z}$ and $\rho/\cos\theta_{2z}$, respectively.

(e) Bisect the angle COD by the line OB.

(f) Join AB. Then the length of the line AB is $\rho\tan\theta$, from which, since ρ is known, θ can be found. Furthermore, the angle χ can be measured. The azimuth of the true dip (referred to the N-S spread) is then $\phi_2+\chi-180°$.

This completes the solution for all the unknown quantities.

RECAPITULATION

This shooting method involves spacing the shot points far apart, with an integral number of spread lengths between each pair of holes and utilizes data obtained from cross spreads at right angles to the main line to give information in the form of correlatable dip vectors at points whose three-dimensional coordinates are known. The contouring of the structural map is facilitated by the fact that the direction of strike and the degree of dip are known for the reflecting points.

The method is economical because the holes are widely spaced and the information obtained for each shot point and for the oblique reflection point between the holes is reliable. Thus the cost of obtaining reliable control is reduced considerably.

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GRADING SYSTEM FOR SEISMIC REFLECTIONS AND CORRELATIONS*

PHIL P. GABY†

ABSTRACT

The modern reflection seismograph places progressively more emphasis on continuous profiling. The use of the continuous profile method automatically makes possible the computation of dip and the plotting of dip cross sections. Fundamentally the accuracy of a dip computed on such a continuous-profile symmetrical record is of the same order as the accuracy of a "correlation" between adjacent records because the dip consists of a continuous-profile correlation over the same length of subsurface base line as that obtained by "correlation" of adjacent, continuous profiles.

Dip computation is the fundamental procedure in areas of discontinuous correlation. Further, the use of dip and of correlation provides two essentially independent approaches to the determination of subsurface structure. The combination of the two is used to provide more uniformly accurate results than can be had through the use of either one alone.

We require a practical method for sorting and grading the accuracy of dip indications and of correlation, which system should be based on substantially the same fundamentals in each case and should be as free as possible from the vagaries of personal judgment.

A system is outlined which is adapted to both purposes. In evaluating dip attitudes, the grade indicates:

(a) The certainty with which the event may be identified as a true reflection, and
(b) The accuracy of the indicated dip.

Similarly, in evaluating correlation, the grade indicates:

(a) The certainty with which the events being correlated are known to be correlatives, and
(b) The accuracy of the indicated correlation drop.

These grades, placed on the cross section, serve as a guide in sorting out any conflicting information at the time the interpretation (and map) is being made. The use of such grades allows the concentration of all pertinent information in one place where any conflicting evidence can be weighed in terms of relative merit.

PURPOSE

The process of grading seismic data is vital to any seismic exploration program because it is through such grades that we sort out the wheat from the chaff to arrive at an interpretation and determine the dependability and limits of reliability of the resulting contour map. Most companies, or even all companies, recognize the need for such grading, although in general the matter probably is left to the discretion of the individual party chief. Despite the importance of the prob-

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lem, open discussion and particularly written discussion has been limited by the tacit assumption that the principles involved were inextricably tied to experience involving intangibles best left to individual personal judgment. The purpose of the present discussion is that of translating such intangibles into specific concepts defined and illustrated and building around those concepts a complete grading system.

The fundamental purpose of any such grading system is that of conveying to the plotted cross section, or map, an accurate evaluation of the original recording. It is an attempt to concentrate on a single cross section all of the pertinent information from the record. When this has been properly accomplished, all of the individual elements of data (reflections, correlations, etc.) each bearing its own individual grade, may be inspected on the cross section where any discord, one with another, clearly shows together with the individual reliabilities so that the most probable resolution may be obtained. Under any but ideal conditions there will be on the cross section at least some uncertainty produced by contradictory information which must in some manner be reconciled in order to arrive at the correct interpretation. It is frequently possible to eliminate the discord by accepting the preponderance of information, and as a last resort this probably must be done. But it must also be remembered that regional dip will always be in the preponderance and our prime problem is that of locating the anomalous, reverse dip. Particularly with short reversals, the laws of chance invariably account for the recording of a preponderance of regional dip and *on the very same records scattered reverse dips will be recorded.* It is therefore highly essential that we recognize the reversal, regardless of the fact that the anomalous, reverse dips, under such conditions, will be few and very probably of lower quality than the regional dips. During the process of grading, some data can be shown to be too inaccurate and unreliable to merit consideration, so that in addition to a mere indication of relative merit of each individual piece of data, a grading system performs another equally important function: that of preventing any irrelevant and unnecessary confusion from appearing on the cross section.

The modern reflection seismograph places progressively more emphasis on continuous profiling. The use of the continuous-profile method automatically makes possible the computation of dip and the plotting of accurate-dip cross sections. Fundamentally, the accuracy of a single dip, computed on such a continuous profile symmetrical

record, is of the same order as the accuracy of a single correlation between two such adjacent profiles because the dip consists of a continuous-profile correlation over the same length of subsurface base line and involves the same probable weathering errors as the correlation of two such adjacent profiles. Dip computation is the fundamental procedure in areas of discontinuous correlation. Further, the use of dip and of correlation provide two essentially independent approaches to the determination of subsurface structure. The combination of the two can be used, with proper handling, to provide more uniformly accurate results than can be had through use of either one alone.

Granting that a grading system of some sort is desirable in accomplishing this purpose, there is almost an infinite number of possible conventions, and this latitude allows equivalent grades to be written in manners which scarcely resemble one another. Such variation is analogous to the use of English, French, German, etc., to describe the original data. The language chosen should be one familiar to the largest possible group of men and should be natural rather than artificial.

Moreover, various men may issue grades which vary considerably, both as to absolute and relative values, even when the same system is being used by all of them. These differences of opinion occur between individuals concerning relative merits not only of reflections, but also of dip attitudes as well. However, it has been noted that discussion tends to minimize these differences. Hence, the more opportunity afforded graders to discuss the reflection in terms of its salient characteristics, the closer the agreement is likely to be. For instance, a group of competent men might well agree on such features as to whether or not a particular reflection has a reasonable increase of energy, as to whether or not most traces copy the energy reasonably and so forth, for all the qualifications that identify a reflection. Even so, they might disagree as to the value of the reflection if asked to represent it by a single word or letter. The desired consistency in absolute and relative grades can only be accomplished by building the system closely around the fundamental characteristics of the transients we call reflections.

The present effort is directed toward delineation of a system which compels analysis of each reflection in terms of rudimentary characteristics so that the assigned grade will provide a thumbnail sketch of the original reflection including its peculiarities and uncertainties. A

sample chart is presented (Fig. 10) in order to show in pictorial manner the spectrum of reflections with their assigned grades, beginning with samples of extremely high quality and proceeding step by step to the opposite extremes of lowest usable certainty and lowest usable accuracy. In its present form, the chart is offered as an example but by no means as a standard. If, after due discussion and compromise, such a standard can be agreed upon, then the difficult task of grading can be rendered less tedious and very much more uniform in application. Ultimately the chart is intended as a wall mount so that through daily exposure the office personnel will become more and more familiar with it and the grades will conform more and more closely to standard in widely scattered offices. This objective appears well worth while provided only that before adoption the standard can be brought to the highest point of desirability by mutual agreement of the largest possible number of qualified men.

One familiar objection to such proposed standardization is raised by a fairly large group of competent men, who hold that both reflection grades and correlation grades should be scaled upwards in difficult areas so as to avoid "grading out" data. That is, in areas where good reflections are rare, they propose to alter the general level of grades so that the best available reflections will still receive the grade of good. Separation of reflection-certainty grades into four categories as is herein proposed ("Good," "Fair," "Poor," and "Reflection questioned") provides as fine a mesh for screening as has been found to be practical. Various graders, even with only the four categories, will fail on occasions to assign identical grades. How then, in areas where the range of quality is even smaller (no "Good" reflections), can we benefit through trying so segregate that smaller range into four categories? It appears certain that one of two things is true:

(a) We require more than four grades or categories in the average area where the full range of quality is to be encountered and sorted by grade, or

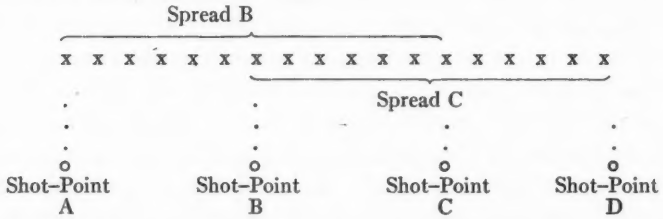
(b) We are not able to use four grades or categories in other areas where the range of quality encountered is smaller.

It seems to be the consensus that four grades are sufficient in all areas, and that even with as many as four grades there will be cases of inconsistent grading (failure to duplicate grades). It therefore appears logical that a single standard should be maintained without regard to areas.

INTRODUCTION

The fundamentals to be conveyed either in reflection grading or in correlation grading are almost entirely dependent upon the type of spread in use, and in the latter case upon the position of one spread with respect to its correlative neighbor. The continuous profiling system has been in use at least since 1936 and because of its inherent advantages it is herein considered as standard. The proposed method of grading can of course be adapted with suitable modification to other types of seismic work, but in what follows we shall consistently have in mind not only a continuous profiling method but one with the following specifications: (a) the subsurface depth points corresponding to edge traces of each spread, duplicate or overlap those of the edge traces of adjacent spreads on both sides and, (b) the depth points across a single record are spaced evenly from the top trace through the shot point (at the center of the spread) and on through the bottom trace.

Such a spread is shown below:



The symbol "*x*" indicates a group of seismometers evenly spaced either in the direction of the profile or at right angles to it.

Correct picking of reflections is automatic on this type of record—one has only to be sure that a reflection is present in order to be sure that it has been correctly picked. Miscorrelation (jumping of a cycle in following the path of the reflection from trace to trace across the record) is reduced to the vanishing point, or even completely eliminated. Grading a reflection, then, is merely a matter of determining:

(a) The "certainty" with which the energy may be classified as reflection energy, and

(b) The "accuracy" with which the dip may be picked.

The same is true of correlations between dips of adjacent records. Depth points are repeated from one record to the adjacent ones on either side, so that, after mathematical adjustment of such factors as shot depth, elevation, and weathering (since the same depth point is normally recorded through different weatherings), the student can

deduce from the reflection times themselves that the correlation between these adjacent profiles is correct. Such mechanical correlation is a very powerful tool and permits a great deal of correlation which would be otherwise impossible. However, it must be used judiciously, since like any other rule it has natural limits. For example, we must assume the dip to be reasonably continuous (without sudden sharp

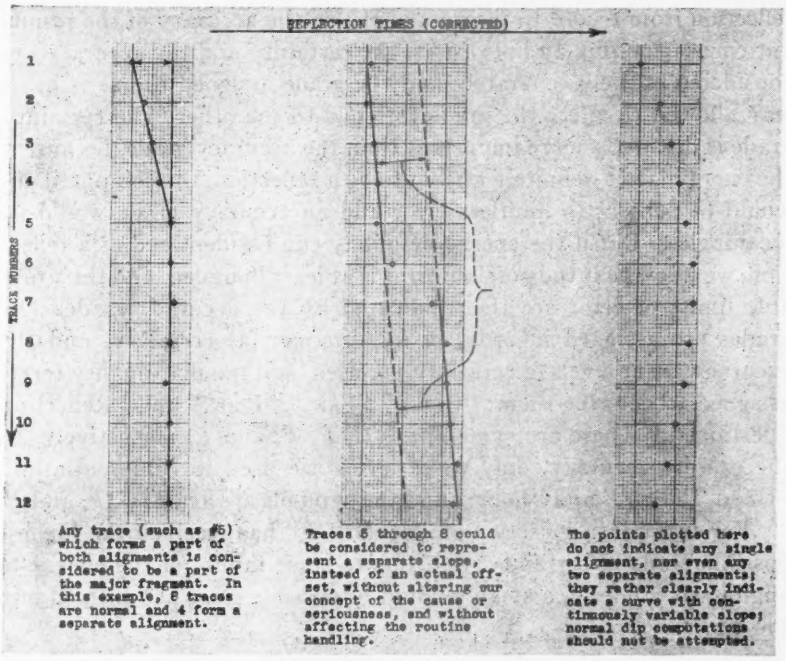

REFLECTION TIMES (CORRECTED)
TRACE NUMBERS
1
2
3
4
5
6
7
8
9
10
11
12
Any trace (such as #5) which forms a part of both alignments is considered to be a part of the major fragment. In this example, 8 traces are normal and 4 form a separate alignment.
Traces 5 through 8 could be considered to represent a separate slope, instead of an actual offset, without altering our concept of the cause or seriousness, and without affecting the routine handling.
The points plotted here do not indicate any single alignment, nor even any two separate alignments; they rather clearly indicate a curve with continuously variable slope; normal dip computations should not be attempted.

FIG. 1, 2, and 3. The alignments above illustrate types of error introduced in dip computation by faulty alignment. For discussion, refer to the section on "Reflection-Dip Accuracy," particularly the sub-section titled "Break in Dip vs. Unique Alignment."

changes in direction or amount) before we may assume the depth points at the edge traces of adjacent profiles are duplicated. In other words, one cannot expect a correspondence of z-depth or of corrected reflection times if there is any vast discordance in dip between records. Such a situation is analogous to the case of a "break-in-dip" within a single dip; thus, if the break occurs within a single reflection (see Fig. 1, 2 and 3), there is usually no way in which a correct estimate of dip may be computed. On the other hand, if the break in dip occurs be-

tween two adjacent records, there is then no way in which "mechanical" correlation may be used.

It is our purpose to grade each reflection once for the certainty with which it can be recognized as a reflection, and to grade it a second time to indicate the accuracy with which the indicated dip can be depended upon. Each correlation is likewise graded on the same two factors: (a), on the certainty with which we are able to follow the reflection from record to record and (b) on the accuracy of the resultant correlation dip. In both cases, the certainty and the accuracy are considered entirely separately and the grade assigned to one is in no way allowed to affect the grade assigned to the other. The certainty grade is distinctly more important than the accuracy grade, because if the energy is not definitely known to be a reflection, the computed dip would be subject to limitless error and an accuracy grade would be meaningless. But if the energy definitely can be identified as a reflection, we know that the possible error is at least bounded, and the probable limits of error are then indicated by the accuracy grade. The grades are assigned in order of importance: (a) certainty, and (b) accuracy. Four levels of certainty are used, and familiar quality terms assigned to describe them: "Good," "Fair," "Poor," and "Reflection questioned." These are symbolized: *G*, *F*, *P*, and *R*, respectively. In the case of accuracy, only three levels are used for differentiation: "Good," "Fair," and "Poor"; and the symbols are again: *G*, *F*, and *P*.

For example, a reflection graded as "*GF*" has received the highest possible grade in certainty, but, due to some failure of the energy to align itself properly, a small amount of possible error has entered into the dip.

REFLECTION CERTAINTY

Since our stated purpose is that of concentrating all of the pertinent information from the records on to the cross section in the form of grades, the following general characteristics will apply to the factors used in grading. They must:

(a) Include the maximum of information obtained from record study.

(b) Exclude from consideration features which may be best observed on the cross section itself.

Various factors included in comparable grading systems have been eliminated on the grounds that they concern information best obtained, not from the study of records, but from the study of the resulting cross section.

FACTORS EXCLUDED

It should be borne in mind that agreement of time increments, or ΔT values, with other reflections on the same record does not necessarily substantiate a reflection. True reflections appearing on a single record may be discordant with each other in the extreme without prejudicing either their merit as reflections or their accuracies as dip attitudes. Likewise, any single dip attitude may agree with others on that record and with adjacent good reflections without itself being a part of a true reflection. In the final analysis, agreement or discordance will show on the cross section where it can be considered in the weighing of the over-all data.

Overlap rightly enjoys considerable popularity at the present date, because record quality is generally improved by its use. But this arrangement also produces certain undesirable characteristics and one of these requires discussion here. An individual group may receive high-amplitude extraneous energy which either does not affect other groups or at least does not affect them at the same moment. Being extraneous, such energy is different from that being received by other groups. For example, with 50 percent overlap, that extraneous energy is added into each of two consecutive traces. The result is that *in the body of reflection* two traces may have abnormal character as compared with the remaining traces. Now if those two traces are identical, although different from the remaining traces, we have what I have termed a "couplet." A couplet, as above defined, can result only from the recording of extraneous energy by a single group of seismometers. On a twelve-trace record, one-sixth of the record (two traces) will appear abnormal and unless the trouble is recognized the reflection involved may be seriously reduced in grade. Bearing in mind that the trouble was occasioned by extraneous noise recorded by one out of thirteen groups, the seriousness with which it is viewed is cut to less than half. Both on a basis of such consideration and from practical observation, such couplets not only may be but should be almost entirely ignored.

FACTORS INCLUDED

The number of factors considered in arriving at this particular grade have been reduced by careful choice and definition to three: (1) essential copy, (2) elevation, (3) envelope.

These factors we now define:

1. *Essential Copy.*—The minimum requirement for the recognition of a reflection is the presence of essential copy. Particularly with low

quality reflection, large amounts of extraneous energy may be present on the various traces so that no one trace is an exact copy of any other trace over the interval during which a reflection is recorded. But as a minimum it is essential that despite the interference, the fundamental oscillation, trough, peak, and trough *of substantially identical frequency* must be recognizable through the disturbance. This condition

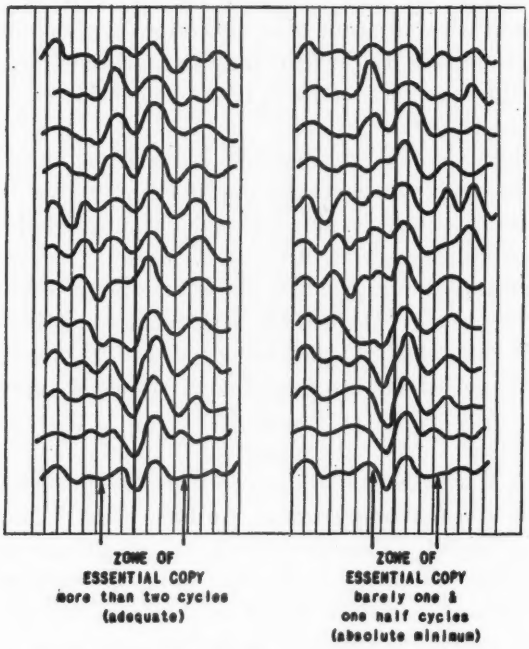


FIG. 4. Illustration of the term "essential copy."

is defined as essential copy. In this connection "essential" has the meaning: "That which belongs to the very nature of a thing and which, therefore, cannot be removed without destroying the thing itself, or its distinguishing characteristic."[1] We are able to demonstrate that a complete reflection includes at last one and one-half cycles of oscillation, and it may persist as long as three cycles, but in any case the life span is brief; and if, in practice, we find a portion of that brief life span so obscured that even essential copy, as above defined, is not recognizable, then quite obviously the certainty with which the energy

[1] Quotation from Webster's Dictionary of Synonyms, first edition.

may be identified as a reflection is reduced. *It is considered necessary that a minimum of one and one-half cycles of essential copy should be present. That is, a zone, or band, of essential copy having the slope of the reflection dip and a minimum breadth of one and one-half cycles must extend across the record* (see Fig. 4).

2. *Elevation.*—A second identifying feature of a reflection is elevation. A returning reflected wave front represents an addition to the

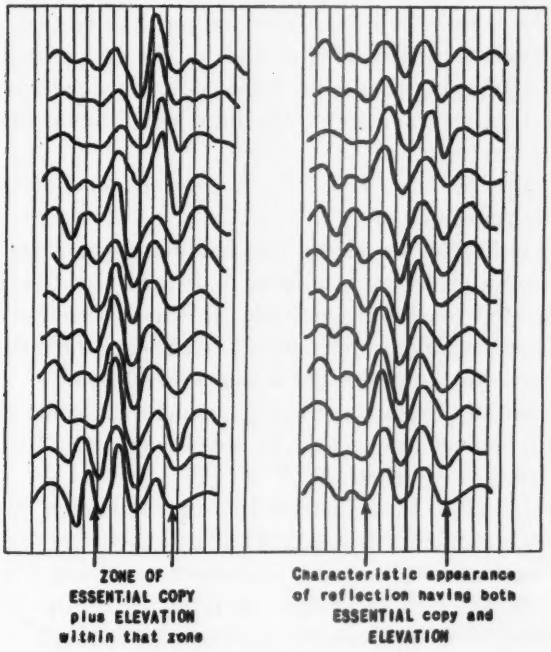


FIG. 5. Illustration of the term "elevation."

total energy being recorded at that instant and should result in an increase in the amplitude of the total energy recorded. If such an increase does not occur, that failure can only be attributed to the weakness of the reflection, as such, or to the presence of conflicting energy from other sources and in either case the certainty of identification is reduced. Of course, in special cases reflections may follow one another so rapidly that a general high amplitude is maintained throughout the duration of two or more reflections. In such case each would be considered as having satisfactory elevation, provided their amplitude is distinctly above that observed in the absence of reflections (see Fig. 5).

3. *Envelope.*—Reflection certainty is greatly enhanced by the use of multiple-trace records whereon the presence of a reflection is recognized by the occurrence of similar energy on a series of adjacent traces. The returning wave front ideally should produce identical oscillation on all traces. In the case of high-quality reflections there is little or no interference and the ideal is realized. In such cases the amplitude is at a minimum near the start, builds up to a maximum near the center of the life span, and diminishes toward the end. We are concerned only with the zone across the record, one and one-half to two cycles while the reflection is recorded, and should not be influenced by energy preceding or following that zone. Obviously, since each trace records the same returning wave front, the ideal condition is realized when three things are true:

(a) Most traces have a distinctive envelope as contrasted to uniform amplitude.
(b) The individual envelopes are of similar form on most traces.
(c) The envelopes may be aligned across the record with the slope indicated by the dip attitude. In this connection "envelope" means the curve which outlines or encloses the reflection, being tangent to the peaks and troughs (see Fig. 6).

Fundamentally these three things, which determine the presence of the quality defined as envelope, include the great bulk of intangibles loosely referred to as "character."

Concerning all of these factors (i.e., essential copy, elevation, and envelope), some leniency is justified by the knowledge that minor disturbances will almost invariably account for some imperfections. Therefore, in order to recognize the presence of any of the above characteristics, it is not considered essential that all traces should evidence it. If 75 percent of the traces clearly indicate the existence of any one characteristic, then that characteristic is considered to be present. For example, with a twenty-trace record, the characteristic is considered present if it may be observed on all but five traces.

The three characteristics listed were designed to overlap conveniently. For example, if a reflection has a definite "envelope," then quite obviously it must also have "elevation," since the envelope is a special type of elevation; and it must also have "essential copy," without which the envelope would be meaningless. So, if it has a distinctive envelope, it automatically has all three factors and therefore receives a certainty grade of "Good." It may fail to have a characteristic envelope, and may still have satisfactory "elevation." In this case, the

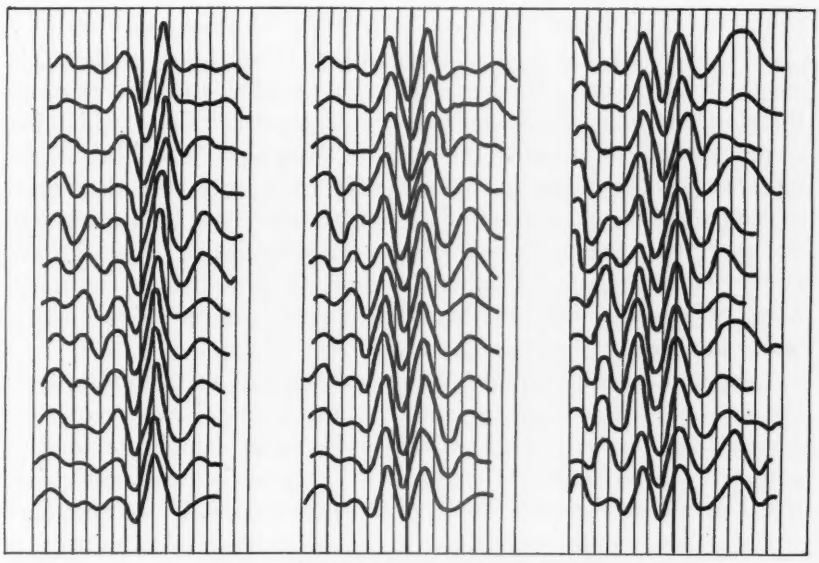

These reflections have distinctive ENVELOPE
in addition to ESSENTIAL COPY and ELEVATION
and hence their CERTAINTY of being true re-
flections is classed as GOOD

FIG. 6. Illustration of the term "envelope."

reflection usually also has "essential copy" and having two of the three characteristics it receives a certainty grade of "Fair." Reflections having neither a distinctive envelope nor suitable elevation, but which do have "essential copy" receive a certainty grade of "Poor." The lowest quality considered permissible consists of questionable reflections which have less than the minimum of one and one-half cycles of "essential copy."

GRADING SCALE—REFLECTION CERTAINTY

Good (*G*). Those reflections having all three qualities: envelope, elevation, and essential copy.
Fair (*F*). Those reflections without distinctive envelope but having the remaining qualities: elevation and essential copy.
Poor (*P*). Those reflections having only essential copy.
Reflection Questioned (R). Questionable reflections, usually those which narrowly fail to have one and one-half cycles of essential copy.

REFLECTION-DIP ACCURACY

FACTORS EXCLUDED

Before proceeding with the discussion of factors considered as controlling the assignment of grades for dip accuracy, we digress slightly

to discuss those items which are to be excluded from consideration.

It is essential that we bear in mind that the certainty with which we recognize the reflection has already been graded, and that we must therefore carefully avoid any tendency to allow certainty (which includes quality) to influence the grade for accuracy. As will be clearly illustrated in the following pages, the highest quality reflections may under certain conditions provide dip attitudes of less than minimum accuracy. Likewise, reflections of low certainty may provide dip attitudes of recognizably reliable accuracy. Obviously then, accuracy must be graded entirely without reference to the reflection quality which has already determined the certainty grade.

The second factor eliminated from consideration actually bears on the matter of dip accuracy, but involves a special case, requiring special handling, and it appears inadvisable to complicate routine grading by including it. The condition arises from circumstances which may cause all reflections on a record to be inaccurate. Use of questionable weathering data is a common example. Such special cases may be accommodated by making a single notation in red pencil on the calculation sheet and on the cross section, and the profile may safely be graded in normal manner except for this notation. Under the proposed handling, attention is clearly called to the exact trouble, which otherwise might not be recognized at a later date. In this manner, the necessary information is placed on the cross section in clear language and without unnecessary complication of routine grading.

Although spread length is a factor of prime importance in evaluating dip accuracy, it is not included in the grading scale for several reasons. The length of spread is indicated on the cross section and thus the information is at hand for use, in conjunction with the grades, in evaluation of the cross section. The grading scale is intended for use with a continuous profiling method, in which case short dip spreads also mean short base lines for correlations so that the accuracy of both is similarly affected. Normally all spreads in a given area are of similar length, so that the matter can safely be eliminated from the grading without upsetting the balance between dip grades vs. correlation grades or disturbing the relative accuracy grades between one profile and the neighboring ones. In case of any particularly short spread, a special notation should be made on the cross section. With this understanding, the grading scale need not be further complicated by including a factor for spread length.

FACTORS INCLUDED

The basic assumption on which all computation of dip depends is that the reflection arises from a plane surface. If that assumption be true, then the individual *reflecting points* associated with the individual traces will be uniformly spaced and the subsurface base line will be approximately one-half the length of the surface base line, and the computations may proceed. But if the reflecting points associated with the individual strings are scattered haphazardly about, then it is usually not possible to arrive at a satisfactory dip increment. There is one and only one present means of determining the continuity and uniformity we require: namely, the alignment from trace to trace across the record should closely approximate a straight line. That statement requires modification only to accommodate "normal step-out," topographic irregularities, determinable weathering irregularities, etc. If, for example, the record has twelve reflection traces, we have twelve individual records of the time required by the sound wave to travel from the shot to some point on the bed and return to the individual seismometer stations. If the reflecting surface involved approximates a plane surface, then the individual reflection times will closely fall about a straight line. Minor deviations from a straight line are not significant. But it is important that there should be no serious and *unaccounted-for* interruptions in the slope of the alignment.

We are all familiar with the problem of determining velocity from a plot of time against distance. The present problem is entirely analogous. Assuming recording stations spaced 10 feet apart, the velocity indicated by any pair of stations would be of low accuracy because of the short base line. If the ties from a number of such consecutive stations fall in close alignment, an accurate velocity may be obtained. And if still another set of consecutive stations indicate a different alignment, then a separate and accurate velocity may be obtained. But any attempt to draw a single alignment by ignoring the interruption in slope would be incorrect. And in the case of dip slopes, the error introduced may be even more serious, since neither the dip itself nor the location of the reflecting point would be correct.

In Figure 1, the vertical scale represents subsurface separation of the individual reflecting points (i.e., consecutive traces of a record) and the horizontal scale represents reflection arrival time. Our inability to determine a single, unique slope is sufficient to indicate that the reflecting surface was not a plane, and since the two slopes differ

by more than our maximum allowable error the dip cannot be computed in the normal fashion. In this particular case, however, the two fragments could be used as two separate dip interpretations and although the accuracy of each will be seriously reduced because of the shortened base line, such handling will at times provide valuable clues to structural features which might otherwise escape unnoticed in the general confusion of contradictory dips produced by ignoring these warning signs.

Similarly Figure 2 represents a case in which there is an offset between the two fragments. This can be accounted for either by a different "cross dip" pertaining to the two fragments, or by an actual difference in depth to the different fragments, as results from erosion or faulting. Again, if dip is to be computed at all, correct handling may be to plot two fragmentary dips—this time with similar dip increments but differing z-depths.

Figure 3 represents the third variant: a reflection from a curved surface. In this case it is not possible by any normal means to compute an accurate dip.

The important fact to keep in mind is that our reflection is made up merely of arrival times and that we are not justified in assuming a plane-surface reflector (the fundamental assumption in all dip computation) in cases where the alignment of arrival times does not bear out that assumption.

In cases where a serious break in dip occurs, the reflection may be plotted on the cross section as a *depth value only*, i.e., without dip arrow. This is indicated on the record by suitable symbol instead of a grade. Such a depth point is plotted in the most likely position on the section as governed by the slope attitudes of other points plotted nearby, unless an estimate of dip (a good guess) can be made from the normal part of the reflection on the record. Fortunately, the exact amount of dip is not absolutely necessary in locating such a depth point, provided the error is not extreme and the erratic dip itself is not plotted. Reflections which do not repeat on enough traces to be used as dips, or have badly distorted dips, may be plotted in this manner, i.e., as depth points without dip indication.

One of the most important considerations concerns the differentiation between minor displacement of one or more traces produced by extraneous energy and that which results directly from a difference in path length. The nature of the reflecting surfaces is not perfect, nor are we able to eliminate entirely the effect of extraneous noise. For

that reason, any single trace of a reflection, no matter how perfect the character appears, may be subject to at least a nominal amount (say 2 or 3 milli seconds) of time displacement. For example, such irregularities can almost always be observed on critical examination of a single reflection recorded on a series of separate shots on one profile. Hence it is not practical to consider individual alignments between pairs of traces. As the number of traces involved in an alignment increases, the base line increases, and the alignment becomes of more and more import. Certainly, if four or more consecutive traces are in alignment, the slope indicated may be considered as indicative of slope of the reflecting interface, and experimental errors become of less import. Hence if four or more traces in close alignment* indicate a slope which is seriously different from the alignment of the remaining traces, then it seems reasonable to conclude that the subsurface reflecting points of the two segments are not adjacent to one another and the dip cannot be computed with any reasonable degree of accuracy, because the actual subsurface base line in such cases is anything but continuous.

1. *Break in Dip versus Unique Alignment.*—Obviously the seriousness of the error produced by such an interruption is dependent on the order of magnitude of the interruption. If the dip increment (ΔT) which would be obtained by ignoring the interruption differs by less than 0.005 second from that of the major fragment extrapolated over the base line of the entire record, then the interruption is ignored; such a minor variation is considered to be just outside the power of resolution of the dip method. But if the interruption produced by change in slope, or produced by horizontal offset between fragments having essentially identical slopes, or produced by the combination of these two faults, is of the order of 0.005 second to 0.010 second, the reflection is considered to have a "*Minor Break in Dip.*" And if such error exceeds 0.010 second, it is termed a "*Serious Break in Dip.*" (See Figs. 1 and 2.)

On the other hand, the alignment may be safely considered as satisfactory if it may be represented by a straight line about which the

* Throughout this discussion, it is understood that each alignment chosen for dip computation will represent the best average alignment at that point on the reflection so that it represents the average of the maximum and minimum slopes which could reasonably be chosen at that point on the reflection. Lead or lag of any or all traces, which is demonstrably produced by recognizable factors (weathering, elevation, etc.) is, of course, allowed for in choosing the alignment, and does not reduce the accuracy provided the computed adjustment would cause the faulty traces to fall into line.

individual reflection times fall, even though the individual times are slightly early or late in a manner safely accounted for by experimental error. Such an alignment is herein termed "unique alignment." The important difference is that there clearly is a single alignment and that deviations therefrom are no more than anticipated experimental error.

2. *Duplicating Alignments and Variable Duplication.*—The probable accuracy of the dip could be determined mathematically from a consideration of the arrival times of the various traces. Suppose such times be read from the nodal points to the left of any particular trough; a most probable slope and also the probable limits of error could be computed. Likewise, the same computations could be made for the nodal points to the right of that trough or at any other particular point on the reflection. Then, in case the two (or more) determinations agree closely, the probable error is very much less than would be true in case the determinations differ seriously. To attempt such computations as a matter of routine certainly is not presently recommended. But we can easily obtain an approximation of that result by carefully noting the deviation from a unique and duplicating alignment. Now if two or more alignments taken from separate parts of a single reflection differ by less than 0.005 second, then we have what is herein termed "*duplicating alignment*" and we are obliged to conclude we have determined the probable dip with the highest accuracy consistent with the powers of resolution of the seismic method being used.

If the individual readings taken from two separate points on the reflection provide ΔT-slopes (or increments) differing by more than 0.005 second, but less than 0.010 second, we term the condition "variable duplication." If the slopes differ by more than 0.010, there is "no duplication" (normally discard one or the other or re-pick both to obtain better agreement).

GRADING SCALE—REFLECTION-DIP ACCURACY

Having completed the definitions of terms to be used, it is now possible to re-group the various factors more conveniently. Each of the two factors listed (alignment and duplication) were divided into three degrees of influence on the accuracy of the dip.

Alignment	*Duplication*
(1) Unique alignment	(1) Duplicating alignment
(2) Minor break in dip	(2) Variable duplication
(3) Serious break in dip	(3) No duplication

If a reflection maintains first-degree accuracy both in "Alignment"

and in "Duplication," it receives the accuracy grade of "Good." In case one factor is of first-degree accuracy and the other second-degree accuracy, the grade is "Fair." And if the reflection maintains only second-degree accuracy in both categories, or first-degree accuracy in "Alignment" and third-degree accuracy in "Duplication," it receives the grade of "Poor." The third degree of accuracy in "Alignment" (i.e., "Serious Break in Dip") is considered to be too inaccurate for use. The grading scale given below reflects these considerations:

1. Good (*G*). Unique alignment and Duplicating Alignment.
2. Fair (*F*). Unique Alignment but Variable Duplication, *or* Minor Break in Dip and Duplicating Alignment.
3. Poor (*P*). Unique Alignment but *no* Duplication, *or* Minor Break in Dip and Variable Duplication.
4. No Dip (*ND*). Serious Break in Dip—plotted as depth point only.

It scarcely seems necessary to point out that the study of alignment can be most accurately and most conveniently accomplished by considering alignment of nodes. Obviously, if the alignment has any appreciable slope, the use of peaks and troughs will complicate matters because of the effect of variable amplitude of oscillation of the individual traces. The nodes, on the other hand, are seldom displaced so that with rare exceptions the vertical spacing of traces is uniform. However, in case of such exceptions, it may be borne in mind that, in an undistorted recording, the node is half way between peak and trough, regardless of temporary displacement of the center of oscillation of the trace, such as may be caused by small amounts of very low-frequency alternating voltage being recorded simultaneously with the reflection.

Normal step-out must be allowed for in considering alignment. There are a number of convenient ways of eliminating the effect of normal step-out to facilitate the study of alignment, particularly of very shallow reflections. One convenient method is illustrated in Figure 9.

CORRELATION CERTAINTY

Here, as in reflection grading, there are two fundamental items to be considered:

(a) Certainty of the correlation.

(b) Accuracy of the correlation drop.

By certainty is meant the degree of confidence with which we may regard a particular trough on one record as being the equivalent of the correlative trough on another record shot somewhere in the same neighborhood. It is one thing to be able to recognize equivalent points

from record to record, and it is another thing entirely to be able accurately to locate the points in the sub-surface from which the reflections came. In order to establish correlation drop accurately, we must be able to locate the corresponding depth points in three-dimensional space. For present purposes, *usually* two dimensions will suffice for the component correlation drop in the direction of the section. In other words, we must have reasonably accurate dips before we can hope to get *accurate* correlations. By having only a *rough* idea of the horizontal displacement of the depth points involved, we should be

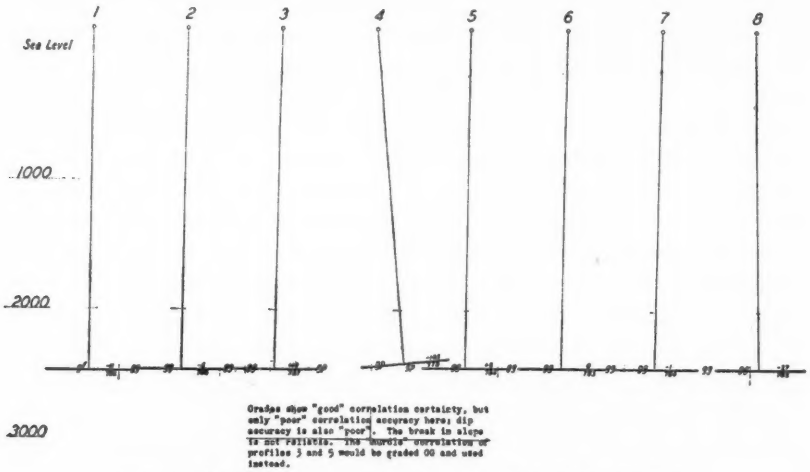


FIG. 7. Illustrating the manner in which the grading system is used to resolve contradictory information.

able to get a *reasonable* representation of the correlation drop if we are *certain* that a correlation exists. Frequently we are able to maintain absolute certainty of correlation through one or more points where it is both impossible and unnecessary to obtain *exact* figures for correlation drops. In such cases, the over-all correlation will be accurate if *terminal* points are accurate, despite the fact it may not be possible to locate accurately one or more intermediate depth points in the intervening space.

If certainty has been graded "*G*" and accuracy "*P*", as in a "*GP*" correlation, the student of the section will recognize that he is at liberty to modify the local correlation drop at his discretion; but, since the certainty is good, he must maintain the same over-all drop between the *last accurately located* reflection point and some future.

reflecting point where the depth point will again be accurately located. This allows considerable latitude in smoothing out errors which otherwise would be "adjusted." For this and other reasons, it becomes particularly advantageous in correlation grading to grade separately for certainty and accuracy. (See Fig. 7.) The actual mechanics of grading these two attributes is relatively simple. Approximately in order of importance, one might list the factors which comprise the certainty of correlation. Then the certainty grade will vary as the particular correlation has all, part, or none of these factors in its favor.

FACTORS EXCLUDED

However, before proceeding to identify the factors which are used under this system of grading, let us first discuss and dispose of a few

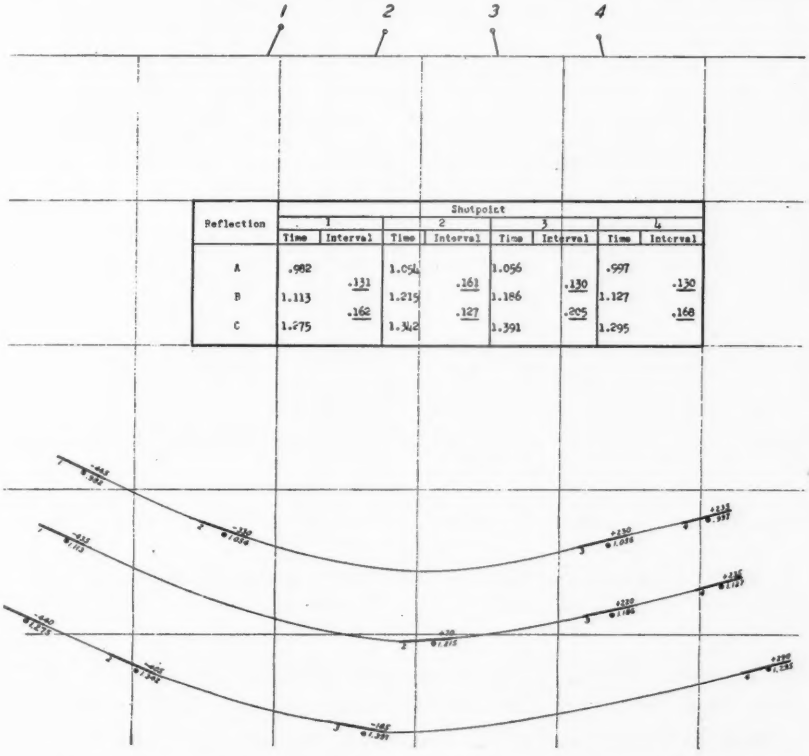


Fig. 8. A rather severe case illustrating how interval may be maintained on the cross section without being at all apparent from the time intervals on the records themselves. Cases of this severity are rare, although milder cases are quite common.

factors which are deliberately eliminated from consideration in grading.

Although the question is controversial, I propose to ignore "interval," as such, in determining *the grade* for correlation certainty. It is obvious (see Fig. 8) that a constant interval may be maintained on the

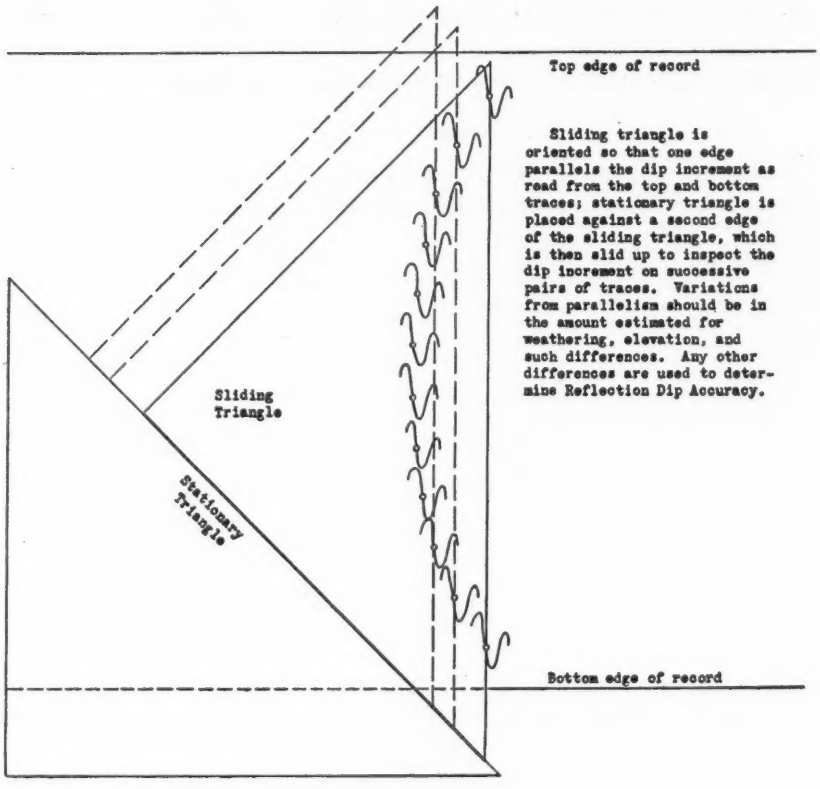

Top edge of record
Sliding triangle is oriented so that one edge parallels the dip increment as read from the top and bottom traces; stationary triangle is placed against a second edge of the sliding triangle, which is then slid up to inspect the dip increment on successive pairs of traces. Variations from parallelism should be in the amount estimated for weathering, elevation, and such differences. Any other differences are used to determine Reflection Dip Accuracy.
Sliding Triangle
Stationary Triangle
Bottom edge of record

FIG. 9. One suggested method useful in studying the alignment of very shallow reflections.

cross section without its being apparent at all on the *records*. This is true whenever a record is obtained near a syncline with reflections coming indiscriminately from the two opposite limbs of the syncline. Then too, it is not always even proper that *geologic interval* be maintained, because thicknesses of geologic members are not always constant. If interval is maintained, the only certain and safe place where

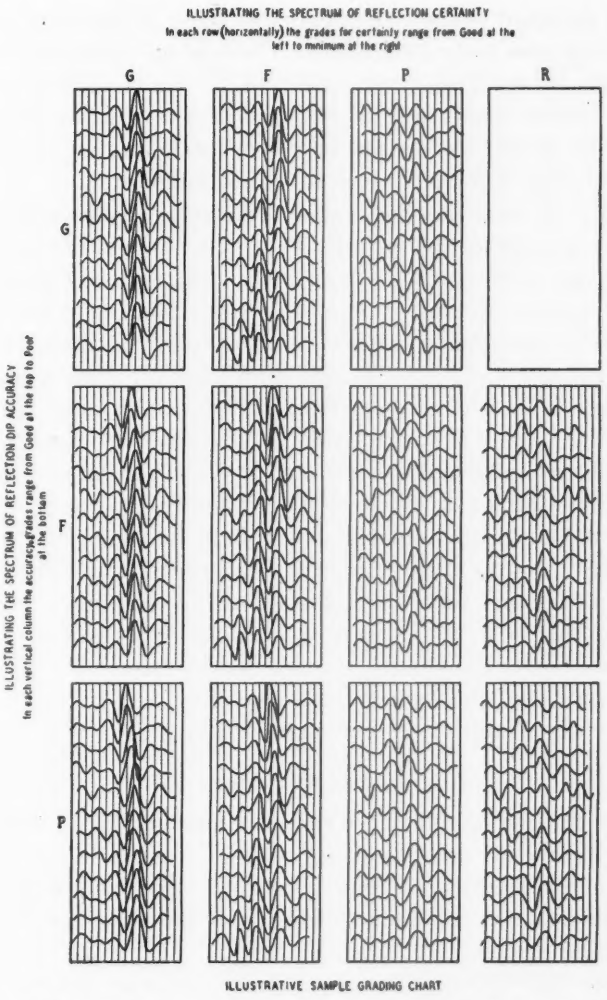

ILLUSTRATING THE SPECTRUM OF REFLECTION CERTAINTY
In each row (horizontally) the grades for certainty range from Good at the left to minimum at the right
G
F
P
R
ILLUSTRATING THE SPECTRUM OF REFLECTION DIP ACCURACY
In each vertical column the accuracy grades range from Good at the top to Poor at the bottom
G
F
P
ILLUSTRATIVE SAMPLE GRADING CHART

FIG. 10. Prepared in accord with the proposed grading system. All reflections thereon are derived from the *GG* reflection (top left) by altering the recording to be removed by successive stages (vertical columns from left to right) the qualities defined as ***envelope***, ***elevation***, and ***essential copy***. Similarly, the accuracy was then altered, step by step, providing the three degrees of accuracies (horizontal rows) labeled *G*, *F*, and *P*.

it may be studied is on the cross section and not on the records. Therefore, since the presence or absence of a true interval is safely determined on the cross section and *not* on the records, this item does not deserve consideration in grading correlations, since by definition these

grades are designed to show the quality of those things which may be observed best *from study of the records*. The student of the cross section will add his observations from study of the cross section to those previously made from study of the records and thus obtain a true picture. Care must be exercised to prevent weighing evidence twice, as would be done if interval were added to the grading.

Secondly, we must resolve against correlating anything which has no basis from study of the records. That is, we should not add a correlation *simply* because it fits the dips. Dip data may be considered in arriving at an over-all evaluation of a cross section, but only *after* the correlation has been graded separately. No amount of resolution could prevent an observer of a cross section from using dip data in determining how certain he is of a correlation. Therefore, this must not be included in the grading of a correlation. As one corollary observation, it is permissible to indicate, with a dotted line, such pseudo-correlations which appear justified on the section but which could not be obtained from record study; but it must be clearly indicated on the section that this is solely a matter of convenience. Thus, pseudo-correlations must stand out at a glance from true correlations (dotted line vs. solid line) rather than merely by some grade or notation. Actually, such connections are not correlations at all, but possibilities arrived at purely from cross-section study, and danger exists that they may confuse the possible existence of faulting or of complex folding.

FACTORS INCLUDED

As with the parallel subject of reflection grading, the factors covering the certainty of correlation may also be grouped in a number of ways. Probably complete agreement cannot be obtained on any single listing of such factors, but the following are those which are considered in the present system.

1. *Time Tie.*—In continuous profiling, the time tie (also called mechanical correlation) stands alone as the prime way of ascertaining the certainty of a correlation. Assuming that proper corrections have been made for hole depth, elevation, and weathering time differences and that the direction and magnitude of dip shown by the two individual reflections being correlated are not discordant,* the method is

* Strictly speaking, uniformity of direction and amount of true dip (maximum dip) is required in order to render the correlation infallible. But it usually is not practicable to shoot a "cross spread" on each profile. Also in most cases the change in direction or

quite infallible. In other words, one must be sure that continuous profiling does actually *exist in the subsurface.* The tie is preserved fairly well even when this is not precisely true, but one must bear this important reservation in mind: regardless of the continuity of instruments on the surface, continuous profiling does not exist if the continuity in the subsurface is broken by any *appreciable* change in the rate or direction of dip, and, obviously, we should not assume continuity which we know does not exist.

2. *Matching Envelope.*—In the grading of reflection certainty, one of the characteristics considered is the existence of a characteristic envelope. A very minor extrapolation of the reasoning applied in that discussion will justify the statement that the certainty of correlation is distinctly enhanced if each of the two correlative reflections has a distinctive envelope, provided the envelopes match as correlated. Likewise, if such envelopes exist, any correlation which results in a mis-matching of envelope is certainly to be viewed as questionable. It is inherent in the present usage of the term, that a matching of envelopes includes not only an agreement in "start" of the two reflections but also the intangible qualification loosely referred to as a "character match." (Since the presence of the envelope is a characteristic of reflections graded with a certainty of good, *matching* envelopes will be found only on correlation between two reflections *both of which* have certainty grade of *G.*)

3. *Elevation.*—The above paragraph illustrates the fact that in correlating two reflections, the factors governing the certainty of the two reflections, as such, also have a bearing on the certainty of correlation. Obviously there can be no certainty of reflection correlation if we are not certain *both* events being correlated are themselves true reflections. The higher the quality of the reflections being correlated, the higher the degree of certainty we may justifiably attach to that correlation. It is for this reason that the existence of suitable elevation of the two correlative reflections is added to the list of factors considered in correlation grading. (Since elevation is characteristic of reflections having a certainty grade of *F* or better, this characteristic will be found present only in cases involving the correlation of reflections of that quality.)

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amount of dip at right angles to the line of profiling will result in a noticeable change in the apparent dip of the individual profiles along the line of profiling. Hence except for critical correlations, it is routine practice (and I think justifiably so) to ignore the "cross dip" while determining the presence or absence of a time tie.

GRADING SCALE—CORRELATION CERTAINTY

Good (*G*). Those correlations having: time tie, elevation, and matching envelopes.
Fair (*F*). Those correlations having either: (A) time tie and elevation, or (B) matching envelope without time tie (change in rate of dip preventing).
Poor (*P*). Those correlations having only time tie.
Questionable (*?*). All other correlations not above included, are indicated by dotted lines and graded with the question-mark symbol.

Further simplification of the above grading scale could be accomplished, but such attempts appear likely to create confusion rather than to accomplish an actual simplification. However, additional remarks are required to accommodate the grading of "hurdles," in which case continuous profiling does not exist even on the surface. In such cases, although the treatment is entirely arbitrary, it is recommended that the correlation be first graded under the above scale with the temporary assumption that a time tie is present, and that the grade be then reduced by one letter. Similarly, a double hurdle would be reduced in grade by two letters and a triple hurdle by three. Longer than triple hurdles do not appear advisable except through the use of a dotted line.

Of course there are numerous cases in which a reflection may be followed with continuous profiling and time tie across one or more records on which a reflection time for correlation either cannot be, or is not, obtained because excessive distortion and confusion makes the reflection time excessively inaccurate. In such cases, since time tie actually exists, the correlation across what *otherwise* would be even a triple hurdle, would be graded in exact accord with the grading scale without reduction in grade (see Fig. 7).

CORRELATION ACCURACY

FACTORS EXCLUDED

As in previous sections, before proceeding with the list of factors considered, it is well to discuss those which are eliminated from consideration.

Correlation accuracy is not in any way influenced by agreement or lack of agreement of the indicated correlation drop and the individual dips. Any tendency to reduce the correlation-accuracy grade merely because the correlation does not agree with the dip would be unjustly to weight the dip information. The converse is also true. Dip accuracy and correlation accuracy are separately graded, each on its own merit. In case they disagree, then either one or the other (or both) has been assigned a low accuracy, or is incorrectly graded, or else some extrane-

ous factor is involved which requires further investigation. Such factors are introduced by incorrect weathering information, or by incorrect elevations, or incorrect locations of one or more profiles, or by bends in the line of profiling, or by differences in amount or direction of shot-point offset, or by inaccurate velocities,* or by any of a number of similar errors. Or the lack of agreement may be caused by a change in the rate or direction of dip *at right angles* to the line of profiling. Particularly in case of important data (critical closure, for example), dip at right angles to the line of profiling should be obtained on each of the points involved if the cause of disagreement is not otherwise ascertained. These matters cannot properly be evaluated from routine record study, and hence are not considered in assigning the grade. When any special study is necessary to resolve discord between dip and correlation, the final grades assigned will reflect the results of the investigation.

A second factor not directly concerned in grading correlation accuracy relates to the usual practice of obtaining more than one record on each profile. The individual records comprising a single profile are frequently obtained from shots of different sizes fired at different depth in the hole and probably recorded through different filters. Adjustments must be made for such variations, and if they are correctly made, the resulting corrected times will closely agree between different records on the same profile. On occasions, however, extraneous factors or errors produce a lack of agreement and in such cases† accurate reflection times cannot be obtained. In such cases the correlation accuracy of all correlations involving such a profile should be reduced as indicated by the amount of observed error. *This is a special case and is not included otherwise in the grading chart or schedule.*

FACTORS INCLUDED

Those factors which are considered in arriving at the grade for correlation accuracy are identified and discussed below.

1. *Dip Accuracy.*—Obviously correlation accuracy is primarily dependent upon our ability to locate the reflecting points approximately

* Incorrect velocities (per se) will produce such trouble when the ratio of interval velocity to average velocity is seriously in error or when a lateral variation in velocity exists.

† As one example, we know that variable shot depth sometimes alters reflection frequencies so that reflections following one another closely will separate differently, producing erratically variable reflection times, etc.

in their correct position. Hence if the accuracy of either or both of the terminal dips is poor, then the accuracy of the correlation itself is reduced.

2. *Reflection-time Accuracy.*—Obviously also, the two reflection times being correlated must be accurate or the correlation drop itself will not be accurate. The best means for determining the accuracy of these time values is to consider whether the trace or traces (usually two traces) on which the times were read fall in general alignment with the remaining traces. Here also the effect of weathering, elevation, etc., must be allowed for. Assuming that such allowance has been made, the reflection time may be regarded as accurate if it falls into the general alignment of all traces, and as probably inaccurate by the amount of its failure to do so. The general alignment across the entire record is obviously more trustworthy than any single observed time and its use as a standard for comparison is therefore well justified (again assuming that allowance has been made for weathering and elevation irregularities, etc.). If the trace falls within 0.005 second of alignment, it is termed to have "reflection-time accuracy."

3. *Duplication.*—Under reflection-dip accuracy we have observed the desirability of agreement between two or more alignments taken at different points within the body of a single reflection. This factor has its counterpart in determining the accuracy of correlations. Reflection times are normally read on the trough of the center one or two traces of each reflection. Whenever possible, it is customary to use the initial or first trough for such purposes. Frequently, the initial trough is distorted because the reflection energy has not yet developed its maximum amplitude and disturbing noises are quite often evidenced. So, for purposes of obtaining the correlative reflection times, we are equally justified in using the second trough and frequently even the third (thus utilizing a maximum of two full cycles). This provides at least two sets of correlative reflection times and the agreement between these sets is a measure of the correlation accuracy. If the two sets of correlative trace values agree within limits of 0.005 second, the condition is termed "duplication." Naturally, a corollary observation is the statement that no agreement between sets can be obtained if only one set is clean enough to justify recording reflection times, and in such cases there is no "duplication."

GRADING SCALE—CORRELATION ACCURACY

Good (*G*)
Dip Accuracy *F* or better, and Reflection-time Accuracy, and Duplication.

Fair (*F*)
Dip accuracy *F* or better, and either Reflection-time Accuracy or Duplication (but not both)
Dip Accuracy *P*, and Reflection-time Accuracy, and Duplication.

Poor (*P*)
Dip Accuracy *F* or better
Or, Dip Accuracy *P*, and either Reflection-time Accuracy, or Duplication (but not both).

Since in each correlation, two reflections are involved, any one characteristic must apply to both reflections in order for that characteristic to be considered present.

ADVANTAGES OBTAINED

The following points of improvement are believed to be inherent in this particular grading system:

(1) A very much clearer understanding is conveyed by separately grading certainty and accuracy.
(2) The validity of a dip and of a correlation under such a grading system are directly comparable, so that in each individual case the more accurate of the two may be accepted.
(3) The personal element is reduced in importance through definition of individual factors on which the grade depends.
(4) Dip information and correlation information are graded independently so that they mutually check each other or, through discord, call attention to the existence of errors requiring investigation rather than averaging.
(5) Resolution of discord can be obtained regardless of whether the conflict involves dip information versus correlation information, or total seismic information versus geological probability.
(6) The system lends itself to the building of a standard visual chart which can be distributed to various field parties to improve standardization of grades between parties working for any one client.

A STUDY OF SEISMIC CHARACTER AND ENERGY RETURN FROM SHOOTING HIGH- AND LOW-VELOCITY EXPLOSIVES*

D. R. DOBYNS†

ABSTRACT

This paper is a report of an investigation of the possibilities of changing the character of reflection records by shooting explosives which vary in detonation velocity from 5000 to 21,000 ft/sec; and also to determine what energy return would result from shooting such various explosives in refraction work. Magnolia Petroleum Company under my direction carried out these investigations on crews in Florida, Mississippi and Texas. A discussion of results and presentation of records will be made.

Quite often the question has arisen as to what difference there is, both as to the quantity of energy and the frequency of that energy, as recorded by seismograph recording instruments, when explosives of widely varying detonation velocities are used in shot holes.

This paper is a report on the results of a series of experiments which were conducted under my direction by Magnolia Petroleum Company. These experiments were conducted along with the regular shooting program, by a refraction crew operating in Bay County, Florida; a reflection crew in Warren County, Mississippi; a reflection crew in Houston County, Texas; and a reflection crew in Trinity County, Texas.

By duplicating as nearly as possible the refraction shots from each of several shotpoints, but using different explosives of widely differing velocities, and measuring the amplitudes of the primary refraction arrivals, it should be possible to determine the relationship as regards the energy return.

The following explosives were used in these refraction experiments:

TABLE 1. EXPLOSIVES USED IN REFRACTION WORK

Explosive	High Rate of Detonation	Absolute Strength
	(*Ft/sec*)	(*Percent*)
Hercules Vibrogel=3	21,300	76
Hercules Gelamite=D	7,500	76
Hercules Hercomite Bag	5,000	78
DuPont Nitramon (4 in.)	15,000	76

* Presented at the Annual Meeting of the Society, Los Angeles, California, March 27, 1947. Manuscript received by Editor June 22, 1947.

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The refraction shot holes in Bay County, Florida were without exception entirely loose, unconsolidated sand from the surface to 90 feet. Since the Vibrogel-3, Gelamite-D, and Hercomite Bag have almost identical absolute strengths, it was only necessary to load the same weight of each in order to have the same explosive strength available.

In the case of the Gelamite-D, Vibrogel-3 and Nitramon, the bulk strengths are almost identical and the Gelamite-D has fair water resistance. The explosives plant of the Hercules Powder Company at Birmingham, Alabama was very helpful in manufacturing for us special cartridges of the Gelamite-D in regular seismograph Spiralock Cartridges. The Hercomite Bag Powder is a low-grade free running ammonium nitrate explosive having no water resistance whatever, therefore, a special procedure had to be devised for loading this explosive. The bulk strength is very low and consequently required a considerably greater volume of explosive to give the same weight as the other two explosives. A joint of Federalite Shothole casing was plugged at one end with a wooden plug. The bag powder was poured into the casing and pushed down into the hole, another joint screwed on and filled, and so on. Since the density of this powder is very low it was necessary to weigh the column of explosive-loaded casing in the hole. The blasting cap was placed in a small piece of the Gelamite-D to insure the starting of detonation in the column, and placed in the top two or three inches of the bag powder. Waxed paper out of the dynamite boxes was wadded up and tamped down on top of the charge, and then a joint full of wet sand was screwed onto the joints of casing loaded with the explosive. The charge then was pushed down in the hole. Because of the low bulk strength it was necessary to load this powder in three holes to get an equivalent weight at the same depth and with about the same column length as the other two explosives. These shots were made along with the regular work of refraction fans and profiles. The recorders were maintained at their same positions, and leaving all the gains of amplifiers the same, duplicate shots were made with the various explosives.

The distances from shot point to detector ranged from 14,000 to 20,000 feet, and the charges ranged from 233 to 300 pounds. The depth to the center of the explosive column ranged from 40 to 70 feet. The order in which the various explosives were shot was varied to eliminate any misinterpretation due to the area around the hole having been disturbed by the preceding shot.

TABLE 2. TABULATION OF AMPLITUDE OF REFRACTION ARRIVALS

Recording Position	Depth	Explosive	High Gain		Low Gain	
			First Break	Percent of V-3	First Break	Percent of V-3
	(*Feet*)	(*Pounds*)	(10^{-2} *in.*)		(10^{-2} *in*)	
91–2A	43	234 Vibrogel-3	179	—	48	—
91-2A	43	234 Gelamite-D	156	87	42	88
91-15	40	234 Vibrogel-3	34		5	
91-15	43	234 Gelamite-D	15	44	3	60
91-15	45	238 Hercomite Bag	33	97	3	80
91-15A	40	234 Vibrogel-3	13		5	
91-15A	43	234 Gelamite-D	11	85	4	80
91-15A	45	238 Hercomite Bag	11	85	5	100
91-15B	40	234 Vibrogel-3	8			
91-15B	43	234 Gelamite-D	6	75		
91-15B	45	238 Hercomite Bag	8	100		
91-9	52	250 Vibrogel-3	34			
91-9	50	250 Hercomite Bag	31	91		
91-10	52	250 Vibrogel-3	87		9	
91-10	50	250 Hercomite Bag	83	95	8	89
91-7	52	250 Vibrogel-3	203		30	
91-7	50	250 Hercomite Bag	186	92	30	150
91-8	52	250 Vibrogel-3	189		47	
91-8	50	250 Hercomite Bag	175	93	45	96
93-18	53	250 Vibrogel-3	26		25	
93-18	60	250 Gelamite-D	21	81	20	80
93-19	53	250 Vibrogel-3	28			
93-19	60	250 Gelamite-D	27	96		
93-5	45	250 Vitrogel-3	30			
93-5	45	250 Hercomite Bag	28	93		
93-6	45	250 Vibrogel-3	35		17	
93-6	45	250 Hercomite Bag	32	91	16	94
93-7	45	250 Vibrogel-3	75		13	
93-7	45	250 Hercomite Bag	70	93	12	92
93-8	45	250 Vibrogel-3	160		40	
93-8	45	250 Hercomite Bag	148	92	38	95
101-1	60	250 Vibrogel-3	—		—	
101-1	60	250 Hercomite Bag	—		—	
101-2	60	250 Vibrogel-3	38		—	
101-2	60	250 Hercomite Bag	27	71	—	

TABLE 2—(*continued*)

Recording Position	Depth	Explosive	High Gain		Low Gain	
			First Break	Percent of V-3	First Break	Percent of V-3
	(*Feet*)	(*Pounds*)	(10^{-2} *in.*)		(10^{-2} *in.*)	
101-3	60	250 Vibrgoel-3	48		—	
101-3	60	250 Hercomite Bag	39	81	—	
101-6	60	250 Vibrgoel-3	46			
101-6	60	250 Hercomite Bag	37	80		
101-7	60	250 Vibrogel-3	108			
101-7	60	250 Hercomite Bag	88	81		
103-2	70	250 Vibrgoel-3	15			
103-2	70	250 Gelamite-D	13	87		
103-6	70	250 Vibrogel-3	66			
103-6	70	250 Gelamite-D	55	83		
103-7	70	250 Vibrogel-3	48			
103-7	70	250 Gelamite-D	27	56		
104-4	60	250 Vibrogel-3	32			
104-4	60	250 Gelamite-D	27	84		
104-1	60	250 Vibrogel-3	103			
104-1	60	250 Gelamite-D	105	102		
104-2	60	250 Vibrogel-3	108			
104-2	60	250 Gelamite-D	79	73		

The tabulation of the measured amplitudes of the primary refraction arrivals is given in Table 2.

Fifteen comparisons of Gelamite-D with Vibrogel-3 showed that only 81 percent as much energy was recorded from the Gelamite-D. Twenty-three comparisons of Hercomite Bag with Vibrogel-3 showed that only 90 percent as much energy was recorded from the Hercomite Bag.

Records showing these refraction arrivals are shown in Figures 1, 2, and 3.

It is apparent from these results that there is some less energy obtained from lower-velocity explosives. Some statements and explanations by Mr. R. W. Lawrence of the Wilmington, Delaware, Laboratories of the Hercules Powder Company as to the probable reasons for this fact follow:

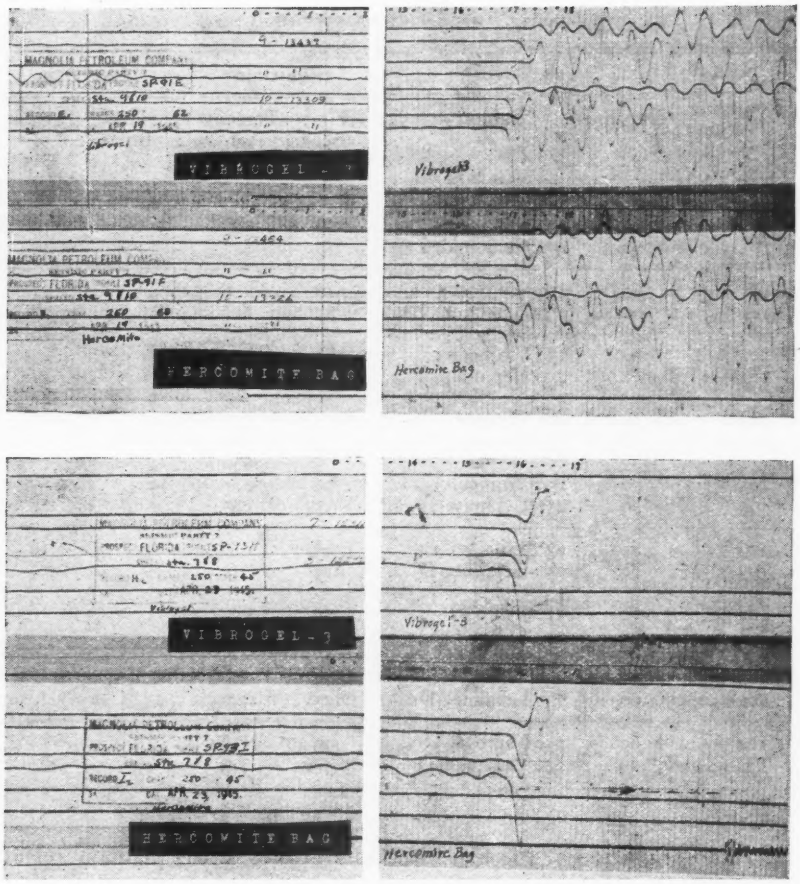

FIG. 1. Comparison of refraction seismograms in Bay County, Florida, using Hercomite Bag and Vibrogel-3 explosives.

"The rate of pressure development is closely dependent on the detonation velocity. In this connection it is desirable to consider the time for the whole explosive charge to detonate and the time for complete detonation to occur at any given point of the explosive column. The first figure depends, of course, only on the detonation velocity and length of the explosive column and is easily calculated, whereas the second figure depends on the length of time for the chemical reactions to occur in the detonation wave and can be roughly estimated from some of our studies on the duration of the detonation zone. The time

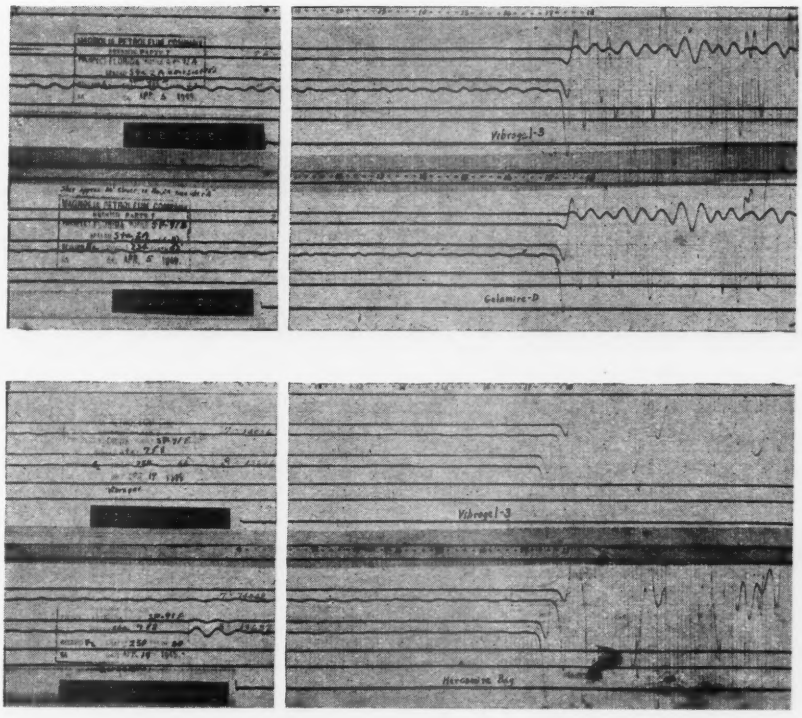

FIG. 2. Comparison of refraction seismograms in Bay County, Florida, using Hercomite Bag, Vibrogel-3, and Gelamite-D explosives.

for detonation to occur is the time for the maximum pressure to develop in the explosive. The approximate times involved are compared in the tabulation below:

Type of Explosive	Detonation Velocity	Time of Pressure Development*	Time for a 10-ft.† Column to Detonate
	(*Ft/sec*)	(*Microseconds*)	(*Microseconds*)
Blasting Gelatin	26,000	0.1–1.0	300
Nitroglycerin	25,000	0.1–1.0	400
Nitroglycerin	5,600	10–15	1800
Vibrogel-3	22,000	1	455
Low-Velocity Ammonium-Nitrate Explosive	5,200	10	1900

* Very approximate.
† About 20 lb. in 2-in. diameter.

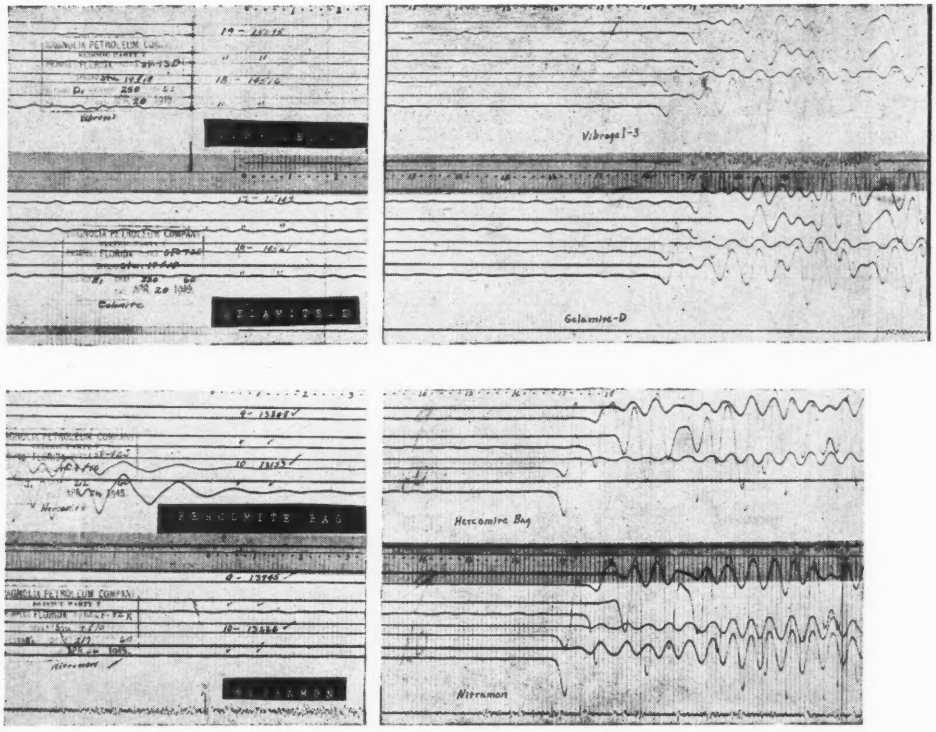

FIG. 3. Comparison of refraction seismograms in Bay County, Florida, using Nitramon, Hercomite Bag, Gelamite-D, and Vibrogel-3 explosives.

"It can be seen that the time for the peak pressure to develop is relatively short compared to the time of detonation of the whole explosive charge.

"A picture of the detonation in explosives may contribute to an understanding of what is happening. We can picture the detonation as involving a detonation wave which travels through a column of explosives. In an explosive like nitroglycerin or blasting gelatin which has a high velocity of detonation (25,000–26,000 ft/sec), it is probable that practically all of the chemical reactions involved take place in the detonation wave during a time interval of less than one millionth of a second. In the detonation wave itself there is, according to theory, a considerable degree of compression which will raise the pressure actually developed in the case of blasting gelatin to something of the order of 2,000,000 lb/in^2. The hot gases immediately behind the detonation wave have a somewhat lower pressure, perhaps one and one-

half million lb/in^2 which falls off rapidly as the explosive expands and does work.

"The sudden high-pressure build-up in the detonation wave of an explosive under water, for example, develops a very high pressure wave or shock wave in the water which has a higher velocity than the normal sound wave. It does, however, fall off rapidly with distance until it has the velocity of a sound wave. When nitroglycerine or blasting gelatin detonates at a low velocity—around 500–6000 ft/sec instead of at the high velocity—the rate of pressure build-up is very much slower. In this case a time of 10 millionths of a second might be required; also about the same time might be required for the maximum pressure to develop in a low-velocity ammonium-nitrate explosive. The velocity and pressure of the shock wave produced will be very much lower. Thus, the fastest and most intense shock waves are produced by the explosives with the highest detonation velocity and highest bulk strength. The initial velocity of the shock wave is roughly proportional to the detonation velocity but the pressure in the shock wave in a liquid increases considerably faster than its velocity. It seems likely that the energy translated into seismic disturbances is probably dependent to a large degree on this initial high-intensity shock wave although the subsequent pressure wave produced by the expanding explosive gases no doubt also contributes additional energy to the seismic disturbances.

"It is of interest to note that an 8-in. diameter × 8-in. length charge of blasting gelatin would detonate in about 25 millionths of a second whereas a 2-in. × 10-ft. column, having about the same weight, would require about 400 millionths of a second."

Reference is also made to an article by Sharpe[1] which gives a mathematical treatise on the generation of elastic waves by explosive pressures. Sharpe concludes that a powder producing a slower application of pressure should produce a smaller amplitude of wave motion. This is borne out by the results of our field tests.

It might be expected that reflection records, obtained through the use of explosives having a very low rate of detonation, would have more low-frequency character than those records obtained through the use of high rate-of-detonation explosives.

In order to determine if such a variation of character can be obtained, experiments were carried out by three different reflection

[1] Joseph A. Sharpe, *The Production of Elastic Waves by Explosion Pressures, Part I. Theory and Empirical Field Observations*, GEOPHYSICS, VII, 144–154 (April, 1942).

crews, and about sixty comparison profiles were obtained using five different explosives.

In Warren County, Mississippi, fifteen comparison profiles were obtained using the following explosives listed in Table 3.

TABLE 3. EXPLOSIVES USED IN WARREN COUNTY, MISSISSIPPI

Explosive	Rate of Detonation
	(*Ft/sec*)
DuPont Hi Velocity	20,000
DuPont Nitramon-S	11,150
Hercules Hercomite Bag	5,000
Hercules Gelamite-D	7,500

Automatic volume control is used in our reflection amplifiers and consequently no noticeable effect would be seen, as to any amplitude change, with the various explosives, more especially since such a small difference in amplitude was seen to exist from our refraction work. The results are shown in Figures 4–8.

A close study of the character and frequency appearance will show that there is no noticeable variation in frequency or character due to the different explosives used.

In Houston County, Texas, twenty-six comparison profiles were obtained using the Gelamite-D, Vibrogel-3, and Hercomite Bag. In

TABLE 4. TABULATION OF THE RESULTS IN WARREN COUNTY, MISSISSIPPI FROM A STUDY OF THESE RECORDS FOR FREQUENCY AND CHARACTER

Profile	Charges Used	Order Shot	Comments
	(*Pounds*)		
341N	5 HV, 4 HB	HV, HB	HV shows some higher frequency
338B-NW	5 HV, 5 GD, 5 GD	HB, GD, HV	HB shows some higher frequency
338B-S	5 HV, 5 N	HV, N	Excellent duplication
340A-NW	4 HB, 5 HV, 5 GD	HB, GD, HV	Good duplication
121N&S	5 HV, 5 GD	HV, GD	Excellent duplication
M-1E&W	5 N, 5 GD	N, GD	Excellent duplication
340A-S	5 HV, 5 HB	HV, HB	Excellent duplication
58BN	5 HB, 5 HV	HV, HB	Excellent duplication
339A-N	5 HB, 5 HV	HV, HB	Good duplication
339-AN	5 HV, 5 GD	GD, HV	Good duplication
37A-N	5 N, 5 HV, 5 GD	N, GD, HV	Good duplication
37ANE	5 N, 5 HV, 5 GD	N, HV, D	Good duplication
37AN&S	5 N, 5 HV, 5 GD	N, GD, HV	Excellent duplication
968	10 HV, 10 GD	Hv, GD	Excellent duplication
95S	5 Hv, 5 GD	GD, HV	Excellent duplication

Abbreviations used in Table: HV = DuPont Hi-Velocity, N = Nitramon
HB = Hercomite Bag, GD = Gelamite-D

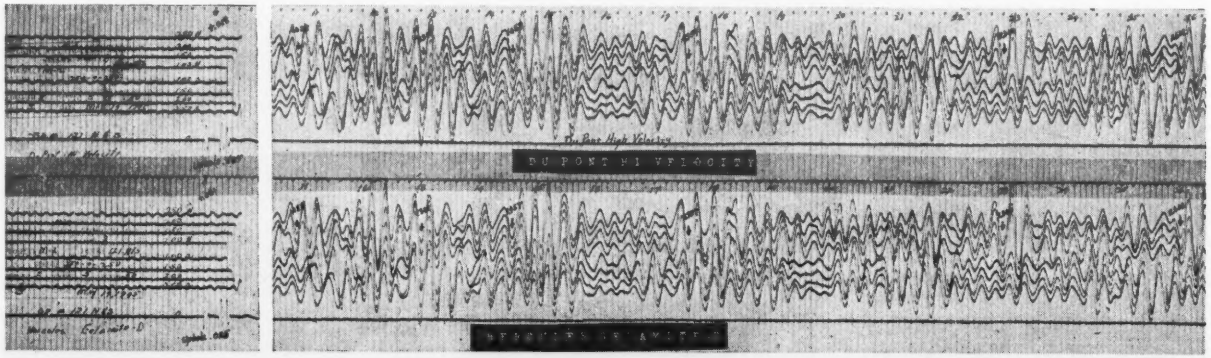

FIG. 4. Comparison of reflection seismograms in Warren County, Mississippi, using Du Pont Hi Velocity and Hercules Gelamite-D explosives.

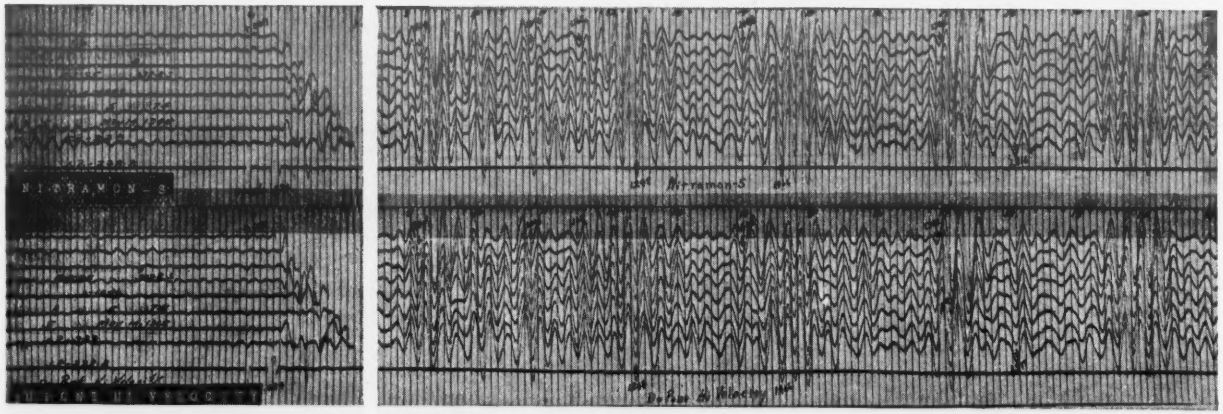

FIG. 5. Comparison of reflection seismograms in Warren County, Mississippi, using Nitramon-S and Du Pont Hi Velocity explosives.

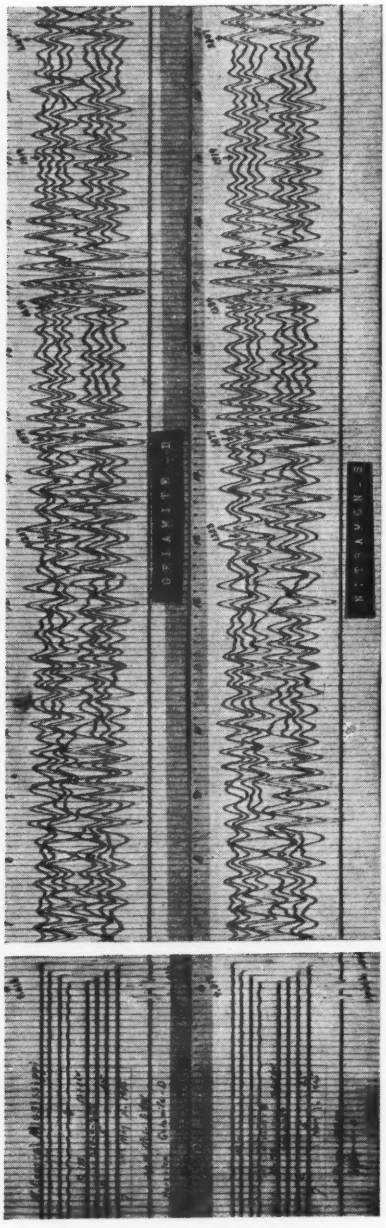

FIG. 6. Comparison of reflection seismograms in Warren County, Mississippi, using Gelamite-D and Nitramon-S explosives.

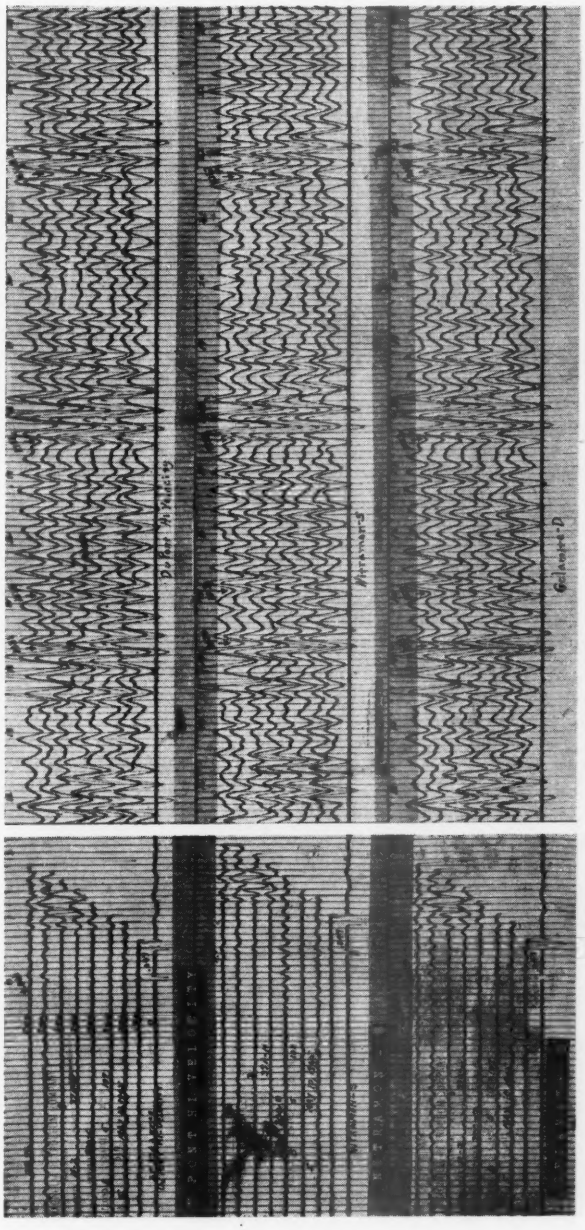

FIG. 7. Comparison of reflection seismograms in Warren County, Mississippi, using Du Pont Hi Velocity. Nitramon-S, and Gelamite-D explosives.

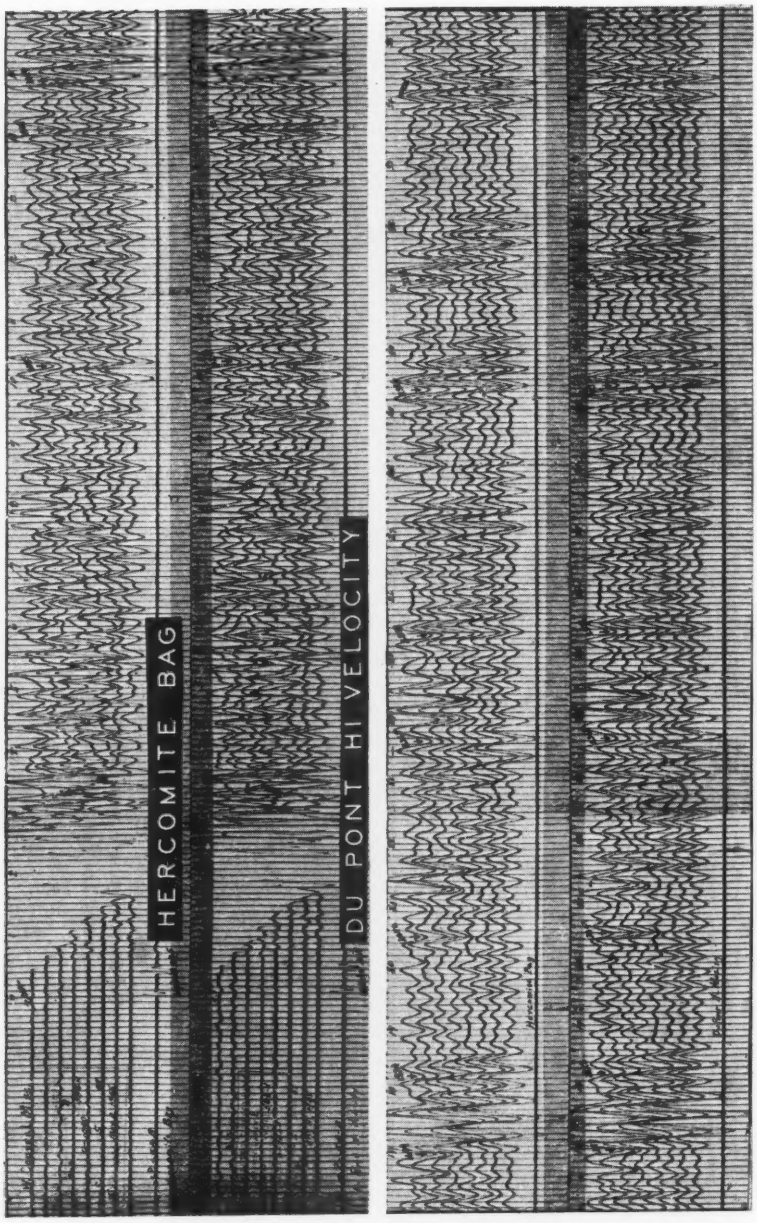

FIG. 8. Comparison of reflection seismograms in Warren County, Mississippi, using Hercomite Bag and Du Pont Hi Velocity explosives.

TABLE 5. A TABULATION OF RESULTS IN HOUSTON COUNTY, TEXAS FROM A STUDY OF THE RECORDS FOR FREQUENCY AND CHARACTER

Profile	Charges Used	Order Shot	Comments
	(*Pounds*)		
15228	1¼V-3, 1¼HB	V-3, HB	V-3 very slightly higher frequency.
1525SW	1¼V-3, 1¼HB	V-3, HB	Perfect duplication
1525NE	1¼V-3, 1¼G-D	V-3, G-D	Perfect duplication
1526SW	1¼V-3, 1¼G-D	G-D, V-3	GD very slightly higher frequency.
1526NE	1¼V-3, 1¼GD, 1¼HB	HB, GD, V-3	Excellent duplication to 1.5 HB& GD, excellent duplication on deeper but V-3 very different
1527NE	1¼V-3, 1¼GD	V-3, GD	Excellent duplication except deep
1527SW	1¼V-3, 1¼GD	V-3, GD	Perfect duplication
1528NE	1¼V-3, 1¼G-D, 1¼HB	HB, V-3, GD	Perfect duplication
1528W	1¼V-3, 1¼GD	GD, V-3	Perfect duplication
1529N	2½V-3, 1¼GD	GD, V-3	GD higher frequency, but probably due to smaller charge.
1593W	2½V-3, 1¼HB, 2½GD	GD, HB, V-3	HB some higher frequency, but probably due to smaller charge
1541S	2½V-3, 2½GD	V-3, GD	Perfect duplication
1549S	2½V-3, 1¼HB, 2½GD	V-3, GD, HB	HB slightly higher frequency, but good duplication & probably due to smaller charge
1589S	2½V-3, 1¼HB, 2½GD	HB, GD, V-3	Excellent duplication
1596E	1¼V-3, 1¼HB, 1¼GD	V-3, HB, GD	V-3 slightly lower frequency
557NW	1¼V-3, 1¼HB, 1¼GD	V-3, HB, GD	Excellent duplication
1332N	5V-3, 2½GD, 1¼HB	HB, V-3, GD	Cannot be compared because of widely varying charges.
1436NE	1¼V-3, 1¼GD, 1¼HB	V-3, HB, GD	Perfect duplication
1634SW	1¼V-3, 1¼GD, 1¼HB	V-3, HB, GD	Excellent duplication
1648N	¼V-3, 1¼HB, 2¼HD	V-3, HB, GD	Not too good comparison
1638E	2½V-3, 1¼HB, 2½GD	V-3, HB, GD	Excellent duplication
1677NE	2½V-3, 1¼HB, 2½GD	V-3, HB, GD	Very good duplication but as in other cases small 1¼ lb. charge shows more high frequency.
1702S	1¼V-3, 1¼HB, 1¼GD	V-3, HB, GD	Good duplication
1721N	1¼V-3 1¼HB, 1¼GD	V-3, HB, GD	Very low quality record almost NR. Last shot some lower frequency.
1725N	1¼V-3, 1¼HB, 1¼GD	V-3, HB, GD	Perfect duplication
1607E	2½V-3, 1¼HB, 2½GD	V-3, HB, GD	Note that another small 1¼ lb. charge shows higher frequency with better separation.

Abbreviations: V-3=Vibrogel-3 (velocity 21,300 ft/sec); GD=Gelamite-D (velocity 7,500 ft/sec); HB=Hercomite Bag (velocity 5,00 ft/sec).

the experiments in Texas no plastic casing was available for loading the bag powder. We used the outer shells of Spiralock cartridges made waterproof on the ends with wax paper and friction tape and weighted down with other such shells filled with sand and taped on top of the loaded cartridge. In Mississippi, joints of plastic casing were sawed up into five-foot joints for loading the bag powder. The records of these tests are shown in Figure 9–12.

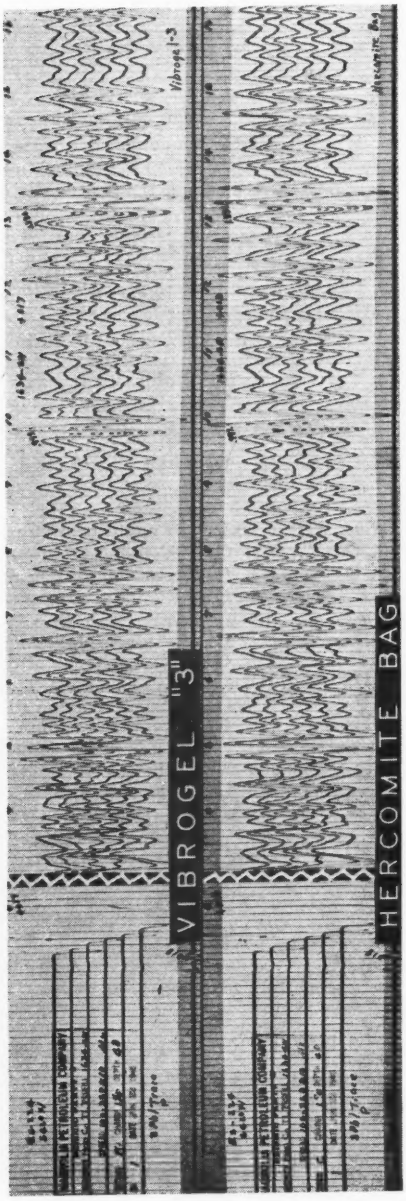

FIG. 9. Comparison of reflection seismograms in Houston County, Texas, using Vibrogel-3 and Hercomite Bag explosives.

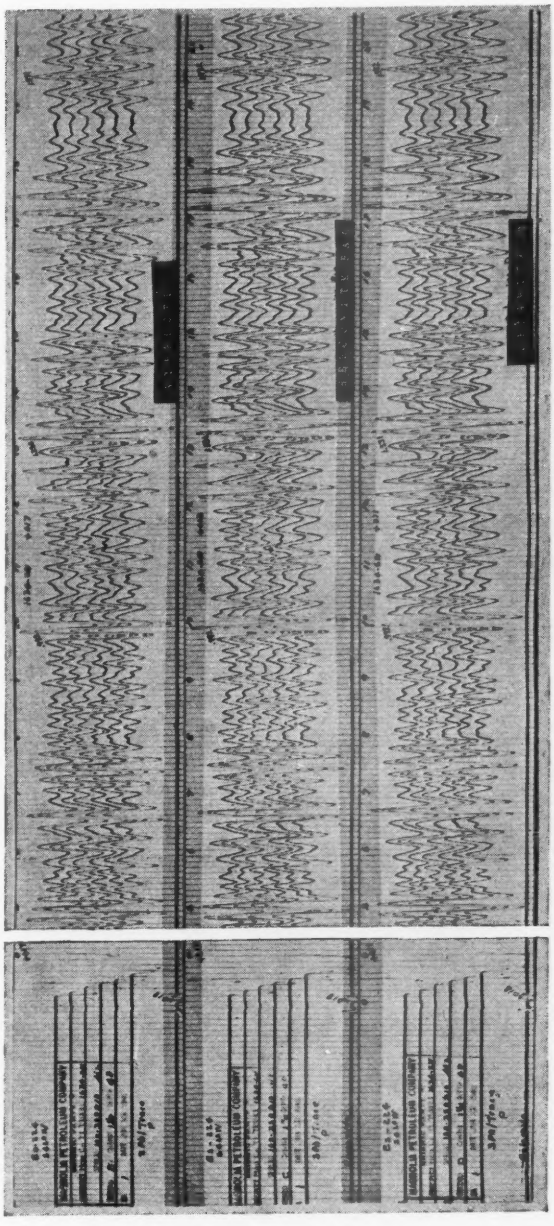

FIG. 10. Comparison of reflection seismograms in Houston County, Texas, using Vibrogel-3, Hercomite Bag, and Gelamite-D explosives.

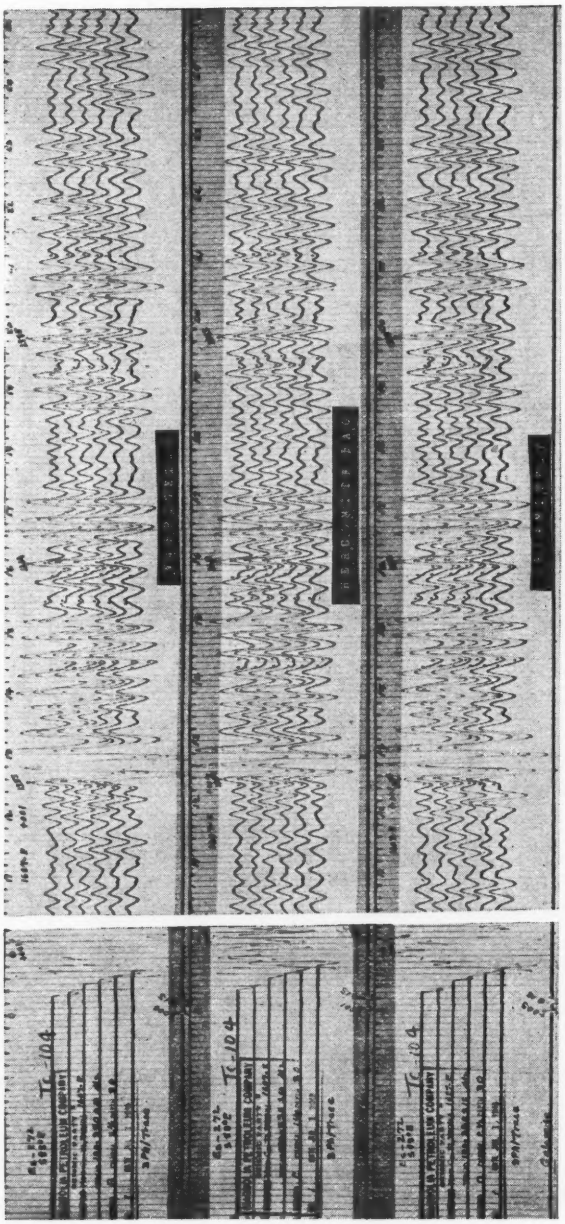

FIG. 11. Comparison of reflection seismograms in Houston County, Texas, using Gelamite-D, Vibrogel-3, and Hercomite Bag explosives.

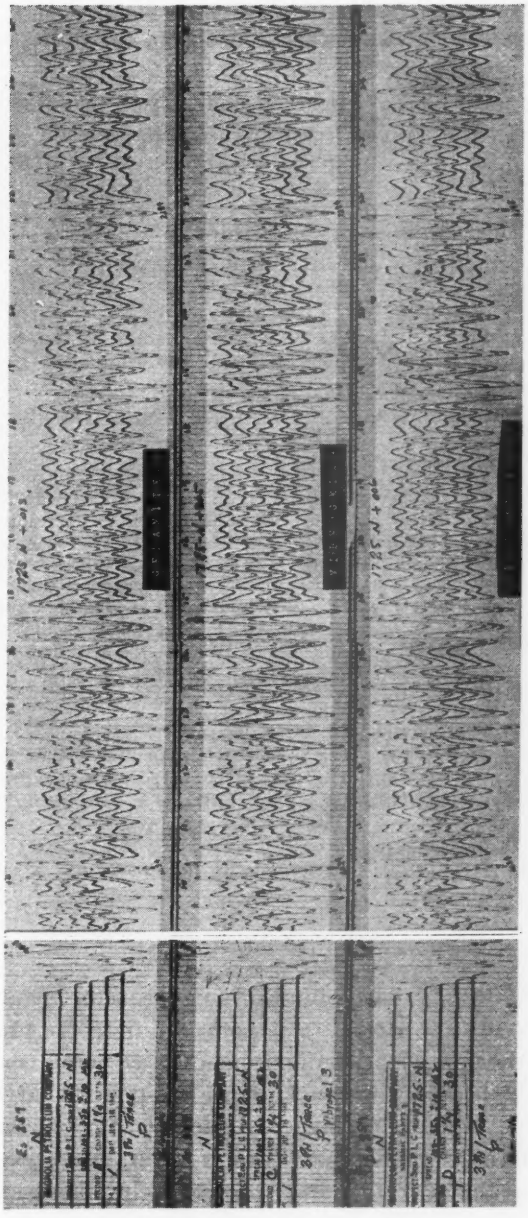

FIG. 12. Comparison of reflection seismograms in Houston County, Texas, using Vibrogel-3, Hercomite Bag, and Gelamite-D explosives.

A close study of the records in Houston County, Texas, for frequency and character shows no variation due to the different explosives used.

In Trinity County, Texas, thirteen comparison profiles were obtained. Here again the Vibrogel-3, Hercomite Bag, and Gelamite-D explosives were used. Records of these tests are given in Figures 13 and 14.

Again a very close study of the records for character and frequency shows no change due to the different explosives used.

TABLE 6. A TABULATION OF RESULTS IN TRINITY COUNTY, TEXAS, FROM A STUDY OF THE RECORDS FOR FREQUENCY AND CHARACTER

Profile	Charges Used	Order Shot	Comments
	(*Pounds*)		
1265N&S	1¼V-3, 1¼GD, 1¼HB	V-3 GD, HB	Excellent duplication
1265N&S	1¼V-3, 1¼GD (50′)	V-3, GD	Excellent duplication
1266N&S	2½V-3, 2½GD, 2½HB	V-3, GD, HB	Perfect duplication
1267N&S	2½V-3, 2½GD, 2½GD	V-3, GD, GD	Poor comparison because of energy difference. Hole fatigued.
1197NW&SE	2½V-3, 2½GD, 2½HB	V-3, GD, HB	HB shows some lower frequency.
1341N&S	2½V-3, 2½GD	V-3, GD	Excellent duplication
1331NE&	2½V-3, 2½GD	V-3, GD	Excellent duplication
1337N&S	2½V-3, 2½GD, 2½HB	V-3, GD, HB	Excellent duplication
1372NW&SE	2½V-3, 2½GD, 2½HB	V-3, GD, HB	Excellent duplication
1395NW&SE	2½V-3, 2½GD, 2½HB	V-3, HB, GD	Excellent duplication
1380NE&SW	2½V-3, 2½GD, 2½HB	V-3, HB, GD	Excellent duplication
1425NW&SE	2½V-3, 2½GD, 2½HB	V-3, HB, GD	Excellent duplication
1450NW&SE	2½V-3, 2½GD, 2½HB	V-3, HB, GD	Excellent duplicaton

Abbreviations: V-3=Vibrogel-3 (velocity 21,300 ft/sec) GD=Gelamite-D (velocity 7,500 ft/sec); HB=Hercomite Bag (velocity 5,000 ft/sec).

CONCLUSION

There apparently are some differences in character when charges of different amounts are used. It was noticed during the progress of these experiments that when one and one-quarter pound shots were used and then duplicated with two and one-half pound charges, there was a noticeable amount of higher-frequency components in the smaller-charge records. This would bear out the statements of Sharpe in his article, that theoretically a small charge, with which is associated a smaller equivalent cavity, should produce wave motion which is richer in high frequency than larger charges.

We cannot, in the three areas investigated, find any noticeable effect on the character or general frequency appearance of reflection

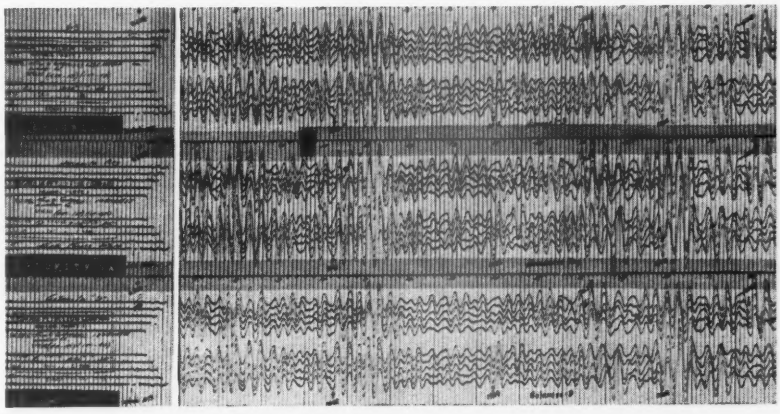

FIG. 13. Comparison of reflection seismograms in Trinity County, Texas, using Vibrogel-3, Hercomite Bag, and Gelamite-D explosives.

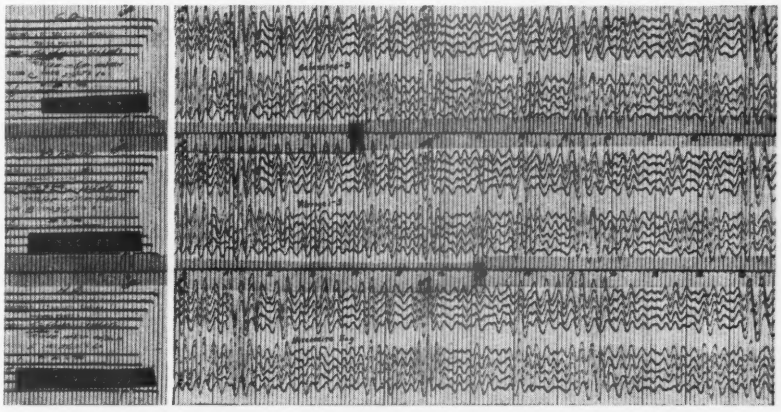

FIG. 14. Comparison of reflection seismograms in Trinity County, Texas, using Gelamite-D, Vibrogel-3, and Hercomite Bag explosives.

records due to the use of the different explosives which ranged in detonation velocity from 5000 to 21,300 ft/sec. A study of the refraction records for character also shows no variation due to the different explosives.

ACKNOWLEDGMENTS

The writer wishes to thank the Hercules Powder Company and the DuPont Company for their interest and assistance in carrying out these experiments. He also wishes to thank the Magnolia Party Chiefs W. M. Tottenham, W. H. Seifert, Perry R. Love and R. M. Nugent, and the observers and shooters on these crews for their full cooperation and assistance. Finally he wishes to express his appreciation to the Magnolia Petroleum Company for permission to publish this paper.

MICROSEISMS IN NEW ENGLAND—CASE HISTORY OF A STORM*

L. DON LEET†

ABSTRACT

A microseismic storm recorded at the Harvard Seismograph Station November 14–16, 1945 is analyzed. Associated meteorological conditions are described. Rayleigh waves and Q-waves are identified. Rayleigh waves are used to determine the direction of approach of the microseisms. It is found that the microseisms did not radiate from the center of the barometric low and that at the height of the storm they approached the station from several directions. The position of the cold front associated with the storm correlated better than that of the barometric low with the directions from which microseisms were observed.

INTRODUCTION

Several years ago, the writer[1] published the results of an attempt to establish the types of wave motion represented by microseisms. The study was based on records of the Harvard Seismograph Station, for the most part, where horizontal motion was recorded by Milne-Shaw seismographs and vertical motion by a Benioff. Installation of horizontal Benioffs and increase in recording-drum speeds greatly improved the data available at this station and made possible the new results of the present investigation. Failure to identify Rayleigh waves in 1934 is now known to have been due to the fact that the records then used could not be read to the required degree of precision. Apparent directions of approach reported then were unaffected by that difficulty.

During the years which separated that study from the present one, microseisms came into prominence when techniques were developed for using them to locate hurricanes.[2–6] These are based on triangulation methods of determining the direction in which the microseisms

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† Seismologist in charge, Harvard University seismograph station.

[1] L. Don Leet, Gerlands Beiträge zur Geophysik, 42, 232–245, 1934.

[2] J. Emilio Ramirez, S. J., Bull. Seis. Soc. Am., 30, 35–84 and 139–178, 1940.

[3] Marion H. Gilmore, Trans. Am. Geophys. Union, 27, 466–473, 1946.

[4] Marion H. Gilmore, Bull. Seis. Soc. Am., 36, 89–119, 1946.

[5] Beno Gutenberg, Trans. Am. Geophys. Union, 27, 111–117, 1946.

[6] J. B. Macelwane, S. J., Bull. Seis. Soc. Am., 36, 81–82, 1946.

are traveling as they pass closely spaced tripartite networks, and are independent of the type of wave involved.

The type or types of waves represented by microseisms, however, is not yet fully established. Statistical discussions of phase differences between vertical and horizontal components[7] led Lee to the conclusion that "although the phase differences between the components are variable, they are generally grouped around certain values, in accordance with the theory of Rayleigh waves approaching from neighboring directions. The absence of Love waves is confirmed, for if Love waves of appreciable magnitude had been superposed upon the Rayleigh waves, the phases of the horizontal movements would have been unrelated to those of the vertical movements." This, of course, is not a conclusive method by which to establish the details of the nature of microseismic or any other type of wave motion. The problem is to identify a wave type by the motion it causes as it passes. For this purpose, a single isolated group analyzed in detail should give more positive proof than a hundred preponderance coefficients.

Ramirez[2] in St. Louis followed attempts in New England[1] to analyze the motion of a particle in the path of microseisms. He confirmed the significant observation that under certain conditions the motion on one horizontal component is of a pattern independent of that on the other, while the vertical matches only one of them. Using records of microseisms from the New England hurricane of September 21, 1938, at a time when waves approached St. Louis from practically due east as determined by a tripartite network analysis of arrival times, he found Rayleigh waves on the east-west and vertical components. The particle moved up-east-down-west, the correct sense for Rayleigh waves travelling from east to west.[8,9] At the same time, however, there was large motion on the north-south component in an independent pattern. He concluded from this that Rayleigh waves are present among microseisms. With reference to the simultaneous motion transverse to the direction of the Rayleigh waves' travel, however, his conclusions were, "These waves may be independent waves of the same type, which in turn may be due (1) to another source of microseisms, a fact which is very unlikely if one may judge from the readings of the arrival times; or (2) to refraction and reflection of microseismic waves from the same source, which may be quite in

[7] A. W. Lee, Proc. Roy. Soc. London, A866, 149, 183–199, 1935.
[8] L. Don Leet, Pub. Dom. Obs. Ottawa, VII, 6, 1931.
[9] L. Don Leet, Am. Scientist, 34, 198–211, 1946.

keeping with their variable amplitudinal character and their smaller average amplitude. Finally, it may be that the waves across the direction of propagation of microseisms are not independent at all, but form part of the motion of the particle and this is in either of two ways: (1) the particle moves in a plane ellipse, but the plane of the ellipse wobbles obliquely back and forth and in and out of the plane of propagation; or (2) the particle moves in a space curve, in the form of a screw wave or of a more complicated movement."

No reasons are given for excluding the obvious possibility that they are Q-waves from the same direction and source as the Rayleigh waves. Wobbling of the plane of particle motion in the path of simple Rayleigh waves has never been observed where conditions were controlled, as with the atomic bomb or dynamite blasts as sources.[9,10] If the waves were advancing by a screw-type mechanism producing particle motion in three directions, the patterns on vertical and both horizontals would bear a constant relationship to each other. The fact that they do not, seems sufficient to justify ruling out that explanation.

In spite of the practical use being made of microseisms in locating hurricanes, and the volumes of literature which have been devoted to a discussion of their nature and origin, there are still many fundamental problems unsolved.[11] First among these is the need for determining the type or types of waves which constitute microseisms. We are fumbling in the dark until that problem is solved. Secondly, we apparently need more studies of the fully detailed case history type, as opposed to general statistical discussions of amplitudes and periods, before enough data will be available for determining the mechanism by which microseisms are generated and the conditions which govern their transmission to distant points.

CASE HISTORY OF A MICROSEISMIC STORM IN NEW ENGLAND, NOVEMBER 14–16, 1945

The weather map for 06–30 U.T. (6 hours 30 minutes Universal Time, that is, Greenwich Civil Time. This is used throughout this discussion and on illustrations), Wednesday, November 14, 1945, shows that at that time pressure was moderately low off Florida and high off Cape Hatteras as well as over the interior of the continent. At

[10] L. Don Leet, Bull. Seis. Soc. Am., 29, 487–496, 1939.
[11] L. M. Murphy, Trans. Am. Geophys. Union, 27, 777–780, 1946.

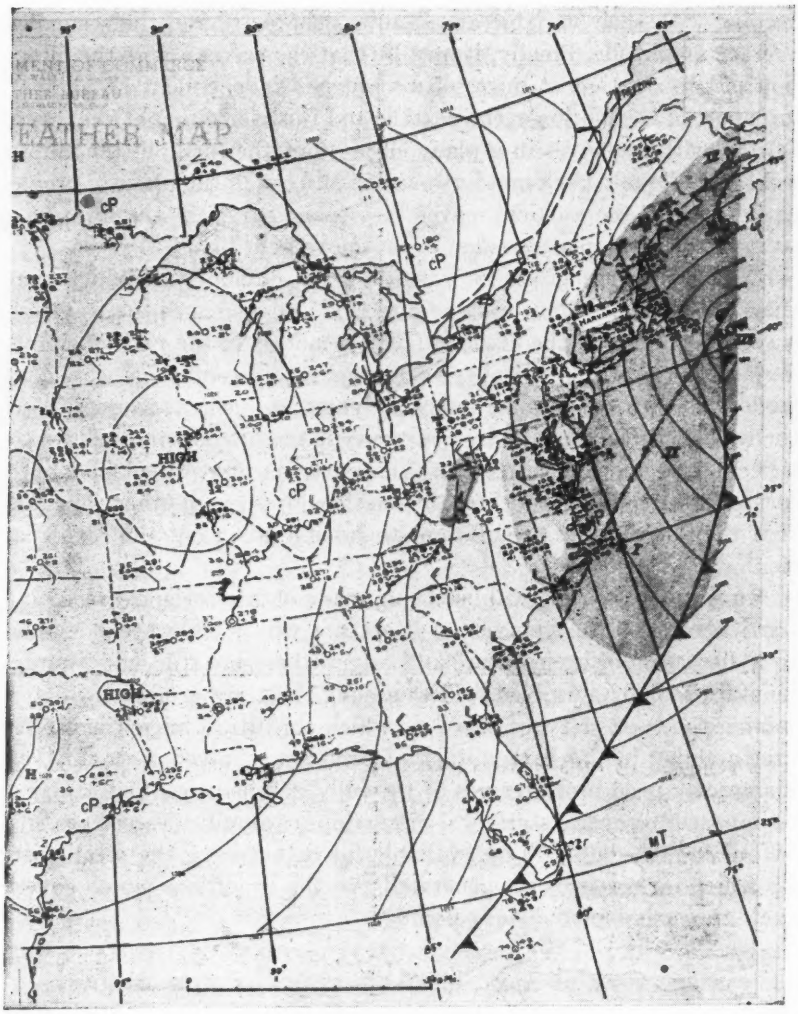

FIG. 1. U. S. Weather Map for 06–30, November 15, 1945.

the same time, a cold front extended roughly parallel to the coast, from Maine through Long Island to northern Georgia.

Twelve hours later, at 18–30, the northern half of this cold front had moved slightly offshore as an occluded front, while the southern half pivoted on Cape Hatteras and also moved offshore. An extra-tropical cyclonic circulation was developing around a low-pressure area over Hatteras. This is called position I.

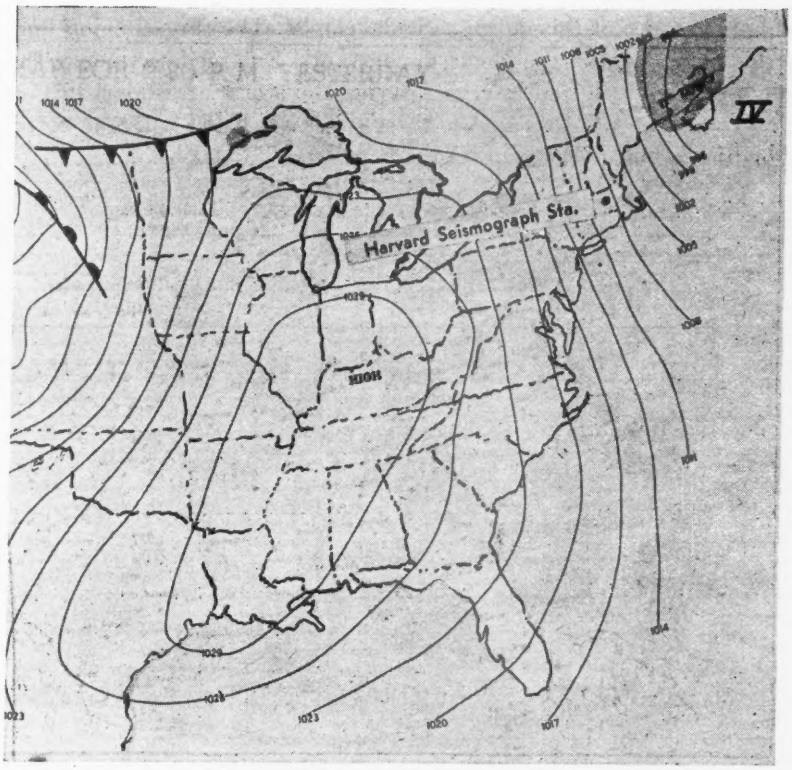

FIG. 2. U. S. Weather Map for 18–30, November 15, 1945.

Twelve hours later, at 06–30, November 15, 1945, the low had advanced to a position southeast of Cap Cod, with a cold front stringing out behind it like the tail of a comet. This condition is shown in Figure 1, on which the position of the low at 6-hour intervals is marked I, II, and III.

Twelve hours later, at 18–30, the low was in position IV over the Gulf of St. Lawrence, as shown on Figures 1 and 2.

Twelve hours later, at 06–30, November 16, 1945, the influence of this low was no longer apparent on the U. S. weather map, and pressure was high over the entire eastern half of the continent.

During the formation and passage of this low, a microseismic storm was recorded on the Benioff seismographs of the Harvard Seismograph Station, at Harvard, Massachusetts. A section of the vertical-component long-period record from 13-30 November 14 to 13–30 November 15, 1945, is shown in Figure 3 to illustrate the gen-

eral appearance of this storm as it developed. The three Benioff long period components have identical constants. Enlarged sections of the microseisms at selected intervals during the storm are shown in Figures 4, 5, 6, and 7. In Table 1, these times are listed with the corresponding positions of the low, for comparison.

TABLE 1. CHECK LIST OF MICROSEISMS SELECTED FOR ILLUSTRATIONS, AND CORRESPONDING POSITIONS OF LOW-PRESSURE AREA

Time (U.T.)	Micoseisms	Position of Low (Fig. 1)
Nov. 14, 1945		
18–30	none	I
Nov. 15, 1945		
00–19	Fig. 4	II
06–30	Fig. 4	III
09–30	Fig. 5	
10–06		
13–31		
15–02	Fig. 6	IV
18–30		
19–02	Fig. 6	
Nov. 16, 1945		
01–54	Fig. 7	
11–27		

Certain groups of microseisms to which particular attention is directed in the following discussion are numbered from 1 through 38 for ease of reference, and so copied as to stand out clearly in Figures 4–7.

The beginning of the microseismic storm can practically be assigned to group 1, Figure 4, just after 00–19, November 15, when the low was in position II. The increase in amplitude occurs in a similar pattern on the vertical and north-south, with the east-west practically at rest as compared with its motion before and after the time of group 1. The ground moved north-up-south-down. This motion is produced by a Rayleigh wave reaching the instruments from the south. Group 2 offers a minor puzzle. The vertical seems to be more nearly in step with the east-west than the north-south, and the sense of particle motion is that for a Rayleigh wave from the east. The difficulty is that the horizontal leads the vertical motion by half a cycle in developing the increase in amplitude, which is not observed elsewhere.

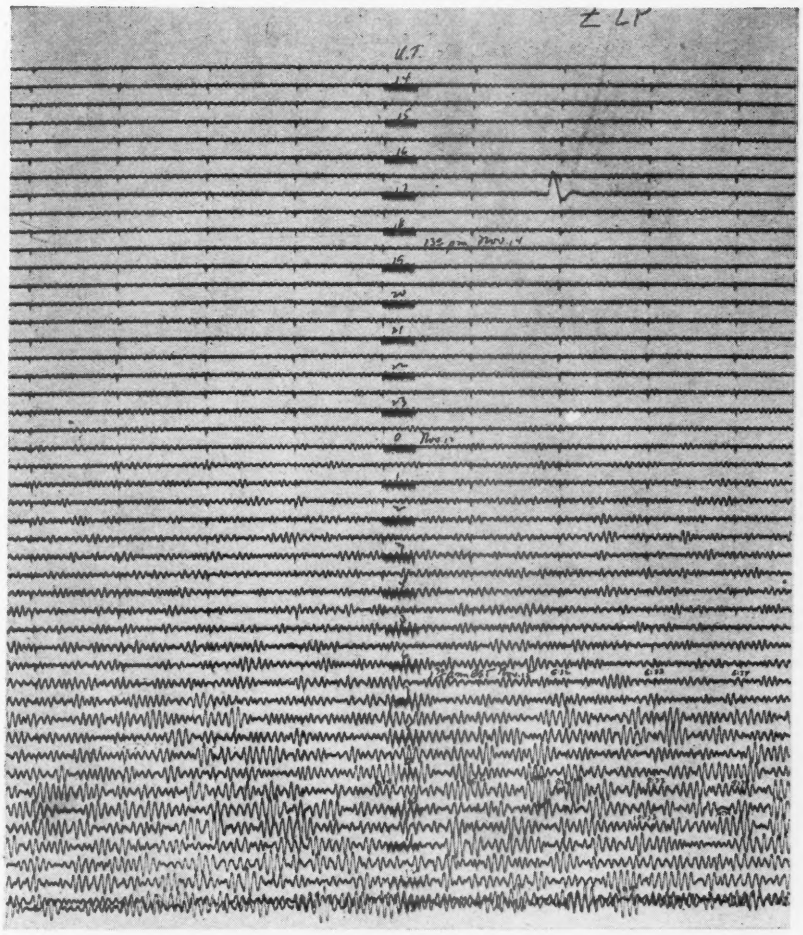

FIG. 3. Section of Harvard Seismograph Station's Benioff Long-Period Vertical record from 13–30, November 15, 1945.

Groups 3, 4, 5, 6, and 7 show the vertical and north-south in parallel patterns of increasing and decreasing amplitudes, with the east-west in independent patterns. Wherever there are more than 3 complete oscillations, it seems probable that more than one wave train is involved. That is the reason for marking 5, 6, and 7 as different groups. Groups 4 and 9 do not show the irregularities which separate 5, 6, and 7, but it is highly probable that they represent at least two groups each. In 3, 4, 5, 6, 7, and 9 the motion is caused by Rayleigh waves from the south.

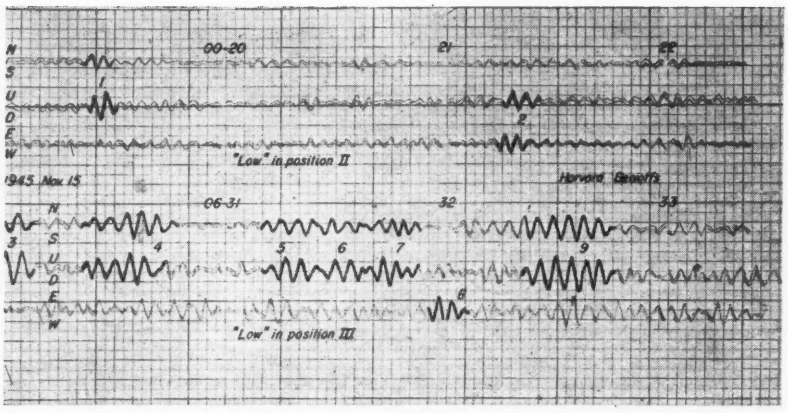

FIG. 4. Microseisms at the Harvard Station as the storm developed. Direction of earth motion indicated by upward and downward motion of trace is shown for each record.

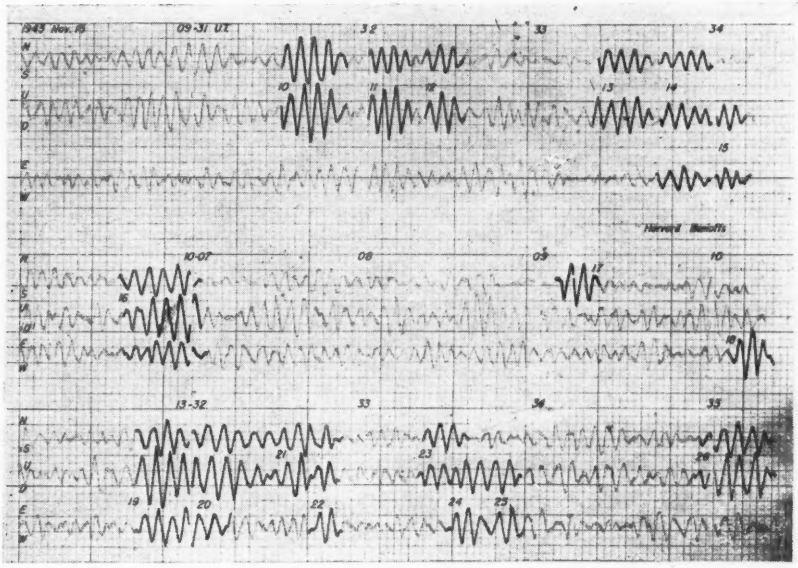

FIG. 5. Microseisms at the Harvard Station as the storm developed.

Group 8, Figure 4, is an example of horizontal motion independent of the vertical and, in this case, of the other horizontal component as well. More striking cases of this type are groups 17 and 18, Figure 5.

Groups 10, 11, 12, and 13, Figure 5, show excellent parallelism between the vertical and the north-south. Group 11 may have a counterpart on the east-west as well but groups 12 and 13 certainly do not and group 10 probably does not. These are Rayleigh waves from the south.

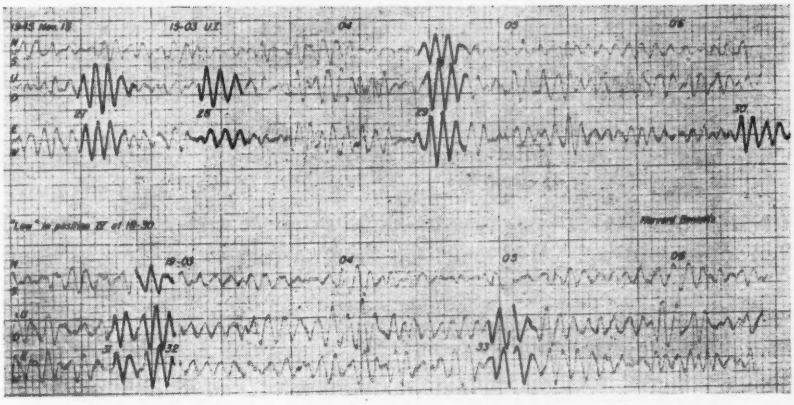

FIG. 6. Microseisms at the Harvard Station as the low moved off the weather map northeast of the station.

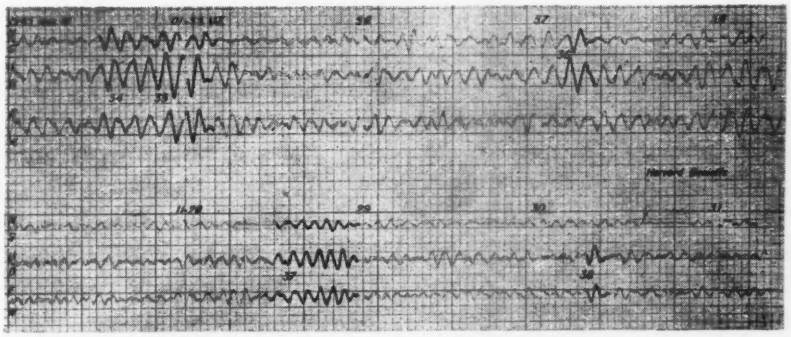

FIG. 7. Microseisms at the Harvard Station in the closing stages of the storm.

After the possibility of synchronism of the east-west in group 11, we have conditions amounting to probability in group 14, where the motion is that of Rayleigh waves from the southeast. Then in group 15, the north-south falls by the wayside and the vertical and east-west show Rayleigh waves from the east. In group 16, the pattern

TABLE 2. DIRECTIONS FROM WHICH MICROSEISMS WERE COMING AS THE STORM ADVANCED

Group No.	Direction from Which Microseisms Came	Position of Low	Direction of Low from Station
1	S	I	S
2	E (?)	II	S
3	S		
4	S		
5	S		
6	S	III	SE
7	S		
8	Q (from S?)		
9	S		
10	S		
11	S		
12	S		
13	S		
14	SE		E
15	E		
16	SE		
17	Q (from E?)		
18	Q (from S?)		
19	SE		
20	SE		
21	S		
22	SE		ENE
23	S		
24	E		
25	E		
26	S		
27	E		
28	E		NE
29	SE		
30	Q (from S?)		
		IV	
31	E		
32	SE		
33	E		
34	SE		
35	SE		
36	S		
37	SE		
38	E		

common to all three is well developed as for Rayleigh waves from practically due southeast. In the midst of this, we still find an occasional group such as 26 as well developed Rayleigh waves from nearly due south.

In groups 27 and 28, we find Rayleigh waves from nearly due east,

followed by group 29 still from the southeast a minute later. Group 30 is another of the relatively rare cases where a pronounced pattern of horizontal motion increase has no counterpart on the vertical seismograph. These have characteristics of Q-waves and it is believed that that is what they are.

By now the low is well to the northeast of the station, but group 31 comes from the east, 32 from the southeast, and 33 from the east.

The microseisms continue fairly strong but slowly losing amplitude into November 16. Seventeen hours after the low was in position IV, after it had filled in or moved too far northeastward to any longer influence the U. S. map, group 37 came in from east southeast and 38 from the east.

In Table 2, these groups of microseisms are listed, with direction indications, for comparison with positions of the low pressure area.

DISCUSSION

The principal features of this microseismic storm are simple and striking. The microseisms began at about the time the atmospheric storm became well formed and its path of travel was definite. The low moved from positions south through southeast to east, then northeast of the Harvard station. Microseisms started to arrive primarily from the south, then from varying angles in the southeast sector, and finally from the east, but their shifts in direction lagged perceptibly behind shifts in the position of the low. Except for a possibility during the first few hours, the microseisms did not come from the center of the low-pressure system defined on weather maps. They never did come from the northeast.

Rayleigh waves dominate the motion. However, there seems to be no doubt about the existence also of horizontal motion with no vertical component. If we are governed by general experience with elastic waves, we sould select as our first working hypothesis the assumption that these are Q-waves from the same source that supplies the Rayleigh waves. Vertical pressures have served as a common source for both.[9]

Possibly most important of all is the observation that as the direction of approach of the Rayleigh waves swung from south through southeast to east, waves from all previously represented directions continued to arrive. As the microseismic storm died down, waves from the southeast were the most numerous, though some from south and

[9] Loc. cit.

some from east could be recognized. This feature would explain the practically universal observation that although microseisms appear to be progressive waves they produce patterns which cannot be followed for more than a very few miles at different seismograph stations. Waves crisscrossing the landscape in several directions would produce the random beat and interference patterns so typical of microseisms.

There has been a tendency in some recent discussions to imply that microseisms radiate from a relatively restricted source, such as the eye of a hurricane, or to generalize from that to the assumption that they do the same from the low center of a well formed extra-tropical storm. It should not be forgotten that if this is ever the case, the microseismic pattern should be traceable across the continent at widely spaced stations just as uniquely as is the elastic wave pattern from an earthquake.

Some of the confusion in published discussions of the cause of microseisms probably traces to attempts to treat all kinds as a single problem and to propose a mechanism which will fit all cases. It is pretty well established that we are lumping under the word microseisms a heterogeneous mixture of phenomena.[3–11] The case history reported here, of course, represents only one special set of conditions and the results observed under those conditions. To complete the discussion, however, one feature of the meteorological data which has been available to seismologists for only a short time and may have a bearing on our search for a clue to causes of microseisms might be worth mentioning. That is the tabulation of information on fronts and air masses. The microseisms of November 14–16, 1945, have been compared with positions of the barometric low on the weather maps, but it should be noted that there is a correlation with the advance of the associated cold front over the ocean. The position of that front in Figure 1, and its probable later positions while microseisms from south, southeast, and east were being recorded, allow for at least a suggestion that it is in some way related to the mechanism which produced the microseisms.

[3–11] Loc. cit.

THE USE OF GEOPHYSICS IN PROSPECTING FOR GOLD AND BASE METALS IN CANADA*

T. KOULOMZINE† AND LEO BROSSARD†

ABSTRACT

The Canadian Shield is an area of Pre-Cambrian rocks some 2,000,000 square miles in extent, which produces a half-billion dollars worth of minerals per year. The geophysical prospecting methods of most use here are magnetic and electrical. Geophysical methods, after recovering from an earlier period of disfavor, are now beginning to be properly appreciated by the local mining industry. Several examples of important recent geophysical discoveries are presented. Future expansion in this field appears inevitable.

The practical value of geophysical prospecting in the search for gold and base metal deposits has gradually become more and more widely recognized by the Canadian mining fraternity. Its introduction into the country around 1920 had given rise to a very skeptical reaction: methods appeared too involved and geologists, who did not fully understand the physical principles, were reluctant to cooperate. This unfavorable feeling prevailed for many years and was aggravated by the unfortunate fact that, in some instances, geophysicists lacked the detailed knowledge of local geology that is essential to proper interpretation. To-day, however, following a number of rather spectacular successes, geophysics has taken its permanent and important place among the various methods of exploration and the nature of the service that it can render to the mining industry is more clearly established: geologists and prospectors realize that, while geophysical surveys directly indicate ore only in exceptional cases, they do supply at a low cost information on the geological structures in drift-covered areas and thereby increase the chances of finding valuable deposits in the later, more expensive, phases of exploration.

The purpose of this paper is to describe briefly the methods most commonly used in Canada and to illustrate by actual examples their effectiveness as well as their limitations.

THE CANADIAN SHIELD

The average annual production of minerals in the Dominion has in recent years exceeded $500,000,000. Altogether, Canada has pro-

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† Koulomzine, Geoffroy, Brossard & Co.

duced to date close to $12,000,000,000, largely derived in the past 25 years. Most of this wealth has been extracted from about 20 mining camps scattered over a vast expanse of Pre-Cambrian rocks known as the Canadian Shield and covering nearly 2,000,000 square miles.

Besides the older and well-known mining districts, such as Sudbury, Cobalt, Porcupine and Kirkland Lake, this area includes a number of younger and fast-growing camps, for instance, Noranda and

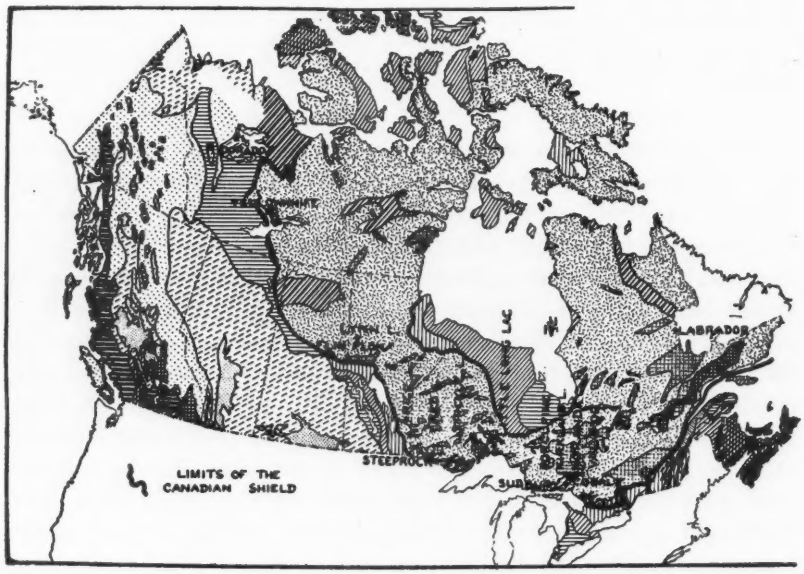

FIG. 1. The Canadian Shield.

Bourlamaque in Quebec, Little Long Lac, Red Lake, Pickle Lake and Steeprock in Ontario, Flin Flon and Rice Lake in Manitoba, Yellowknife and Eldorado, the home of uranium deposits, up in the Northwest Territories. New fields are also being constantly opened up and, for example, important discoveries of iron in Labrador and of nickel at Lynn Lake in Northern Manitoba have recently attracted considerable attention.

The future of the Canadian mining industry appears very bright indeed, but it is fully realized and it has repeatedly been pointed out that further discoveries will have to be more greatly dependent on scientific devices such as geophysics due to the simple fact that over 95 percent of the Pre-Cambrian Shield is covered with a mantle of

glacial deposits commonly ranging up to 100 feet in thickness and frequently attaining 300 feet or more. While vast stretches in the more remote and more inaccessible areas still remain unmapped and totally unexplored, it is probably true to say that, in the vicinity of the above-mentioned mining camps, most or all of the outcrops have already been examined and that the possibilities of standard methods of prospecting have been exhausted. In these areas, therefore, new mines can be found only through an investigation of the rocks underlying the overburden. The formations of the Canadian Shield consist essentially of volcanic and sedimentary series that have been upturned by mountain-building forces during pre-Cambrian time and now dip almost vertically; the detailed structure is complicated by considerable faulting and by the presence of a large number and a great variety of intrusive masses. The cost of working out such a geological picture by borings would be prohibitive and the general rôle of geophysics is to outline under the glacial drift the structures with which ore is most likely to be associated and thus direct subsequent exploration by diamond-drilling to the most favorable spots.

MAGNETOMETER SURVEYS

The two geophysical methods most generally used in prospecting for gold and base metals in Canada are the magnetic and the electrical methods.

Magnetometer work probably accounts for over 95 percent of all geophysical surveys conducted in the Pre-Cambrian Shield: whether the search be for gold or for base metals, they always supply valuable information on the geological structures underlying the overburden; furthermore, the operating technique is simple, resulting in low cost, and readily understood by the average mining man. A tendency is gradually developing at the present time for exploration companies and even for the individual prospectors to operate their own instrument and to consult a specialist for interpretation. This practice, which is likely to grow in coming years, will undoubtedly contribute to a more widespread use of magnetometers; one of its disadvantages, however, has been that some operators were not sufficiently familiar with the basic principles and with the delicate mechanical adjustments necessary to ensure accurate data, so that, in some cases results were inferior to what they could have been.

Instruments most commonly used are of the Schmidt-Askania type; crude dip-needles or other types of needle-magnetometers such

as the Berg are also employed occasionally, but their sensitivity of some 300 to 1000 gammas per degree is far too poor for the great majority of mining properties, where an anomaly of 50 gammas may be of economic significance.

There is a great variety of networks used depending on the object of the survey. If it is intended to trace a very definite structure, such as a highly magnetic dike or a large body of iron ore, sections at relatively wide intervals may be satisfactory, but to outline the detailed features with which gold deposits are associated on the average prospect we have found, after numerous experiments with all sorts of networks, that the minimum practical interval is of 300 feet for the lines and 100 feet for the stations, with some more closely spaced readings usually necessary in strategic sections of limited extent. On looser networks, certain important structures may be missed altogether or be unrecognizable and present no clues suggesting the advisability of more detailed measurements around them.

Interpretation is usually made by means of profiles or of isomagnetic contours. Although a number of geophysicists insist on the superiority of the latter, we see no basis for such claim: while it is very rare that a structure apparent from a study of the contours would not be equally well indicated by profiles, as illustrated by some of the examples cited further on, the contacts and attitude of magnetic bodies are as a rule much more accurately determined by profiles. Furthermore, the use of contours often leads to misinterpretation: for instance, there is no theoretical justification for the widespread tendency to assume that a contact is represented by a particular isomagnetic curve. In some cases, however, contour maps more strikingly illustrate features already disclosed by an examination of the profiles and may be regarded as a useful, secondary tool in the hands of the interpreter.

MAGNETIC-SULPHIDE ORE BODIES

As mentioned before, only a few ore deposits of the Canadian Shield consist of magnetic minerals that can be directly indicated by magnetometer work. One of the most spectacular cases of this type provided the stock sensation of recent years when diamond-drilling of certain magnetic anomalies from the ice of Lake Osisko disclosed the presence of large copper-gold ore bodies on the property of Quemont Mining Corporation, adjoining Noranda on the north. The complete results of the survey are shown below.

No outcrops were available, but over 15 years ago a 900-foot shaft had been sunk near the southern boundary of the property and a relatively large amount of lateral development carried out with negligible ore results. Anomalies D_1 and D_2 were interpreted as being due to a diabase dike and anomalies *K*, *J* and *G* as intrusive masses of older gabbro and magnetic volcanics. Of anomalies *X*, *Y*, *Z*, *U* and *V*, considered to represent either gabbro, or magnetic mineralization in the rhyolite or sulphide ore bodies, the first two proved to be due to gabbro and secondarily introduced magnetite, while copper-zinc-gold deposits were found to underlie anomalies *Z* and *U*.

It is interesting to note that only three important base-metal discoveries were made in Canada in recent years, namely at Quemont, at East Sullivan in Bourlamaque township near Val D'Or and at Lynn Lake in Northern Manitoba, and that all three are directly attributable to geophysical prospecting. This gives an idea of the part that geophysics can be expected to play in future mining developments in the Dominion.

GOLD DEPOSITS

The Val D'Or area provides an excellent text-book illustration of the theory of gold deposition as expounded by W. H. Emmons in his book on "Gold Deposits of the World." As can be seen from Figure 3, most of the mines of the district are located around the margin of the Bourlamaque granodiorite batholith or associated with smaller intrusive plugs of similar composition in the vicinity of the main mass. The economic importance of tracing the contacts of acidic intrusive bodies in the area will therefore be readily understood.

In the light of these considerations, it is extremely interesting to study the part played by magnetometer work in gradually working out the geological picture of the district. Not only were the outlines of the main batholith mostly determined by magnetic surveys but at least two previously unsuspected outlying plugs were thus discovered, namely the Centerpost and the Snowshoe stocks, which lie respectively under heavy overburden and under the waters of lake Demontigny. Subsequent diamond-drilling resulted in the development of the East Sullivan ore body near the Centerpost mass and disclosed numerous gold values of commercial grade in the Snowshoe intrusion. Incidentally, the regional diorite dike which passes just south of the Centerpost mass and in which important gold deposits were later discovered at Louvicourt Goldfields was traced magnetically throughout the

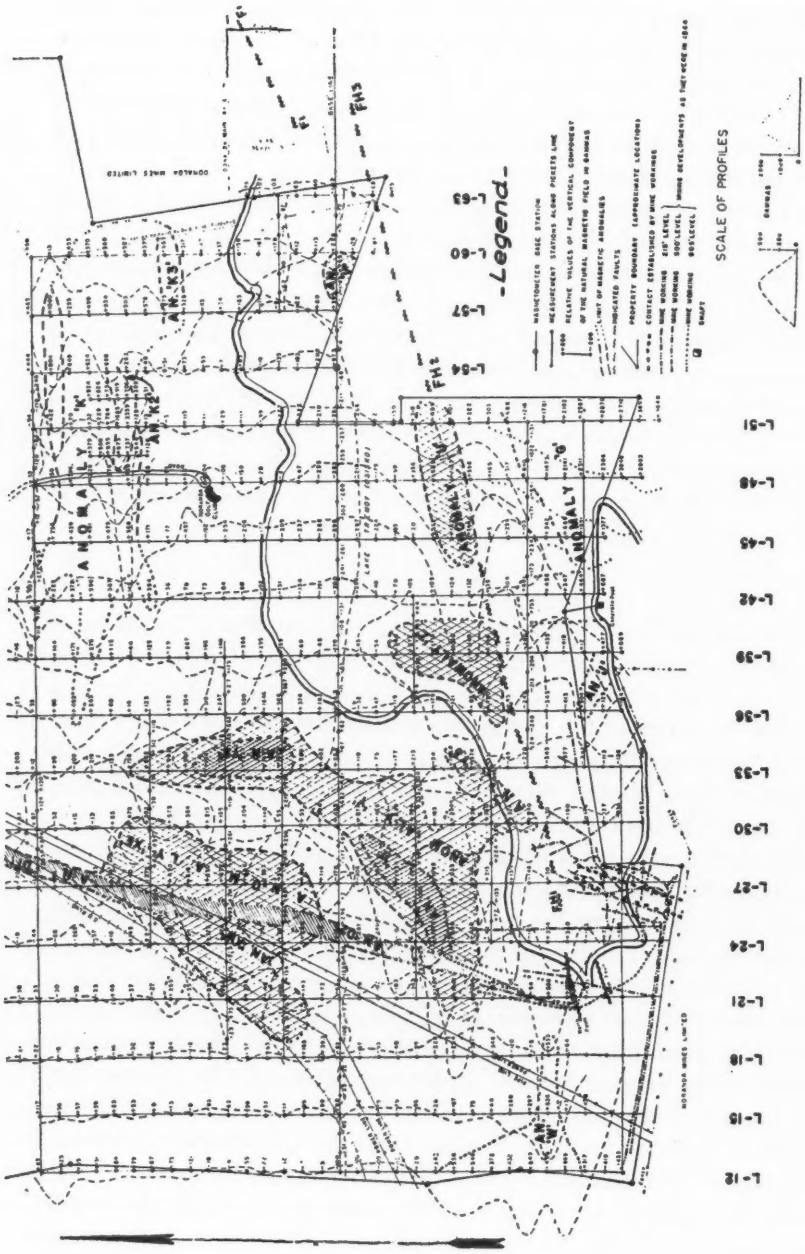

FIG. 2. Results of magnetometer survey on the property of Quemont Mining Corporation.

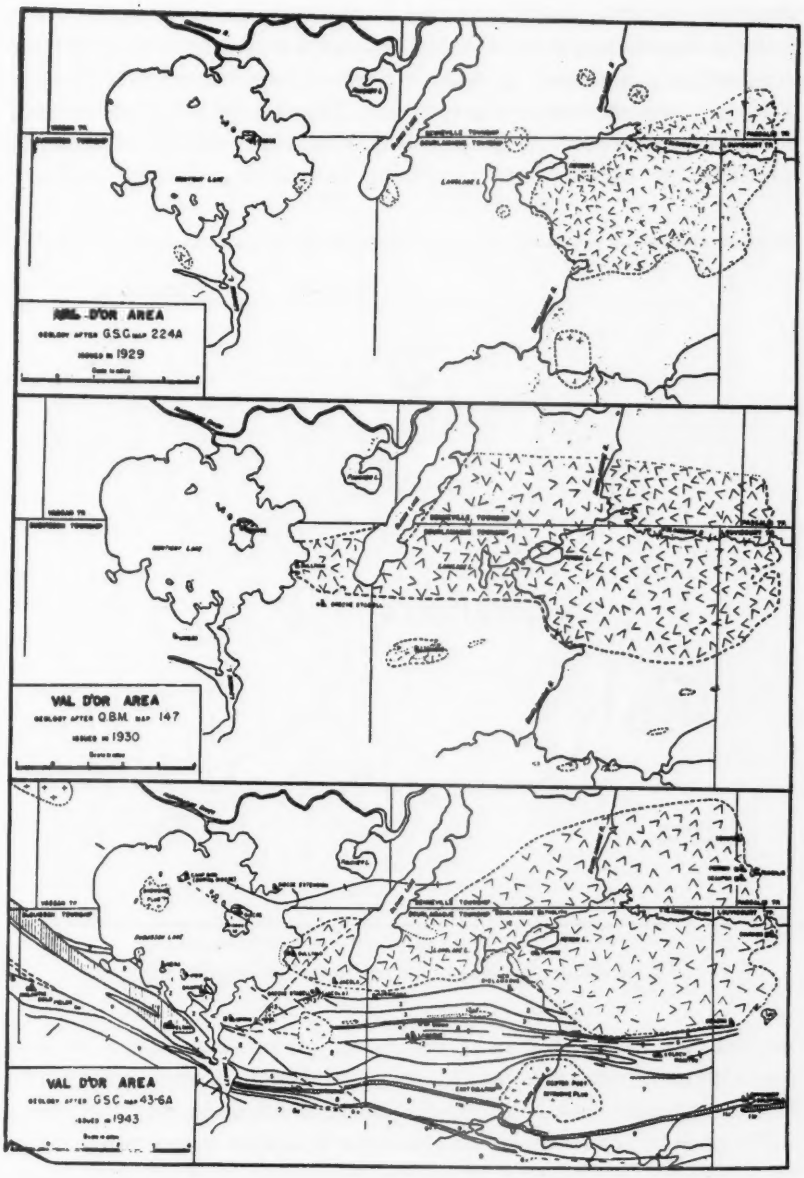

FIG. 3. Gradual working out of geological picture in the Val D'Or area, largely through magnetometer work as explained in the text.

township. Recently, magnetometer work has suggested the possibility that the Bourlamaque batholith, considered as one intrusive unit for the past 20 years, may actually consist of two distinct bodies separated by a narrow tongue of greenstone. This has not yet been verified, but if it proves correct, geophysical indications will have been responsible for turning into promising prospecting ground territory

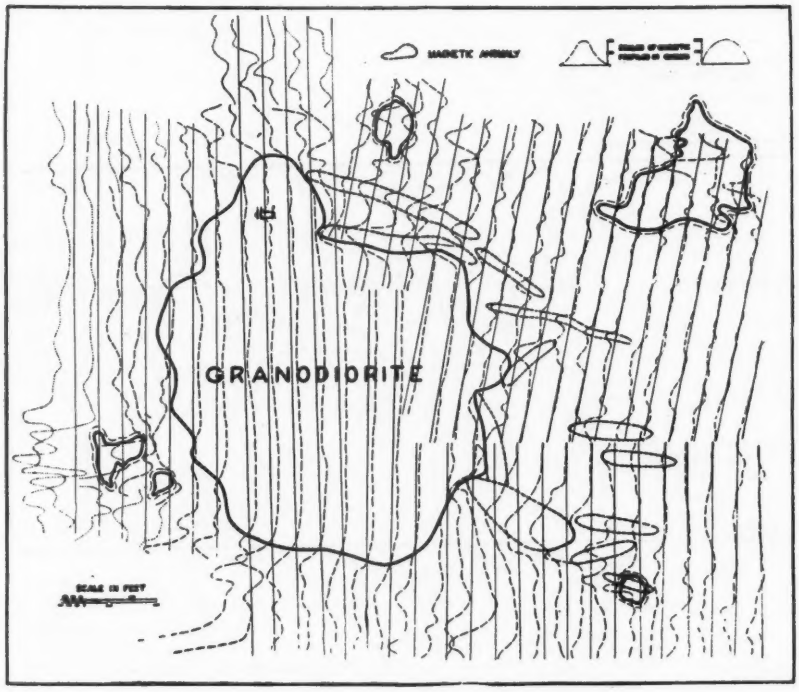

FIG. 4. Magnetic profiles over the Snowshoe intrusive plug.

located right in the heart of a well-known mining camp and heretofore regarded as unfavorable because lying within the intrusive mass.

Similar examples could be multiplied indefinitely, but the above will suffice to show the indirect manner in which magnetometer surveys lead to the discovery of gold mines in drift-covered areas of the Pre-Cambrian Shield by outlining favorable structures.

The detailed results of the magnetometer survey that led to the discovery of the Snowshoe granodiorite plug are shown on Figure 4.

The contrast between the lack of anomalies over the homogeneous intrusive mass and the irregular values obtained over the enclosing greenstone formations is evident at a glance. This is one structure that isomagnetic contours undoubtedly would have shown clearly, but it is also made quite apparent by a study of the magnetic profiles.

AIRBORNE MAGNETOMETERS

During the last war, airborne magnetometers were developed with

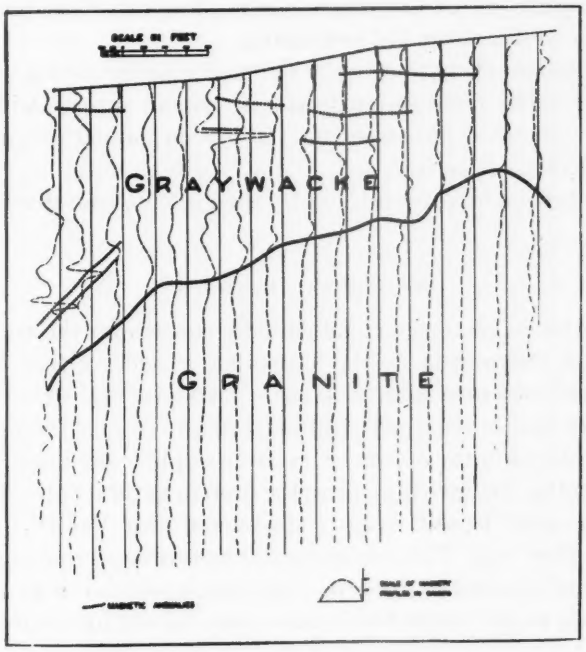

FIG. 5. Magnetic profiles over granite-graywacke contact illustrating significance of small variations.

which, it is claimed, an area of 100 square miles can be surveyed in four hours with results in close agreement with those obtained by ground methods. It is hoped that this technique will eventually permit the reduction of costs to about one tenth of what they are now.

The most serious limitation of any airborne magnetometer is due to the fact that, since measurements have to be taken from above the ground, it is just as though another layer were added to the over-

burden, which is already quite thick over the Pre-Cambrian Shield. and magnetic intensities registered are appreciably lower with a number of small variations blotted out entirely; the trouble is that in numerous cases the interpreter must rely on such minor reactions to determine the location of certain structures, like intrusive contacts, that may be of great economic importance in the search for ore. For instance, Figure 5 shows a contact between graywacke and granite. It will be noticed that, although there is little change in the average intensity over the two types of rocks, the contact is quite clearly indicated by the occurrence of a number of low variations resulting in less regular profiles over the sediments.

It is therefore likely that, while airborne magnetometers will prove of great value for rapid reconnaissances, ground surveys will still remain necessary to work out minute details on mining properties, especially in view of the fact that, in our Canadian bush, lines will still be required, or at least useful, to plot the geology, spot diamond-drill holes, etc. . . .

ELECTRICAL METHODS

While the magnetometer undoubtedly constitutes the most useful geophysical instrument in the Canadian Shield, certain electrical methods are used occasionally to solve particular problems. The self-potential or spontaneous-polarization method is one of the most commonly employed in the search for massive sulphide ore bodies lying at shallow depths. Figure 6 illustrates the drop in natural potential over a copper-zinc-gold deposit recently discovered near Val D'Or. In this case, the work was of an experimental nature and conducted after partial development of the ore body; equipotential lines, however, show clearly that it could hardly have been missed by a self-potential survey.

Electrical surveys can evidently not be carried out under water of lakes or swamps, which cover large areas of the Pre-Cambrian Shield, or during the winter. Recently it has been found possible to slightly extend the duration of their seasonal application by using anti-freeze solutions in the electrodes.

Other electrical methods are of even more restricted application, and present a great variety of principles and techniques depending on the nature of the particular problem that they are intended to solve. Shears and sulphide deposits may be indicated by resistivity measurements, but the overburden covering the Pre-Cambrian Shield is usu-

ally a much better conductor than the underlying bedrock, so that many resistivity anomalies are due to changes in the thickness or in the nature of the overburden.

A new variation of the resistivity method was recently experimented on at the Waite Amulet mine, near Noranda. At this property,

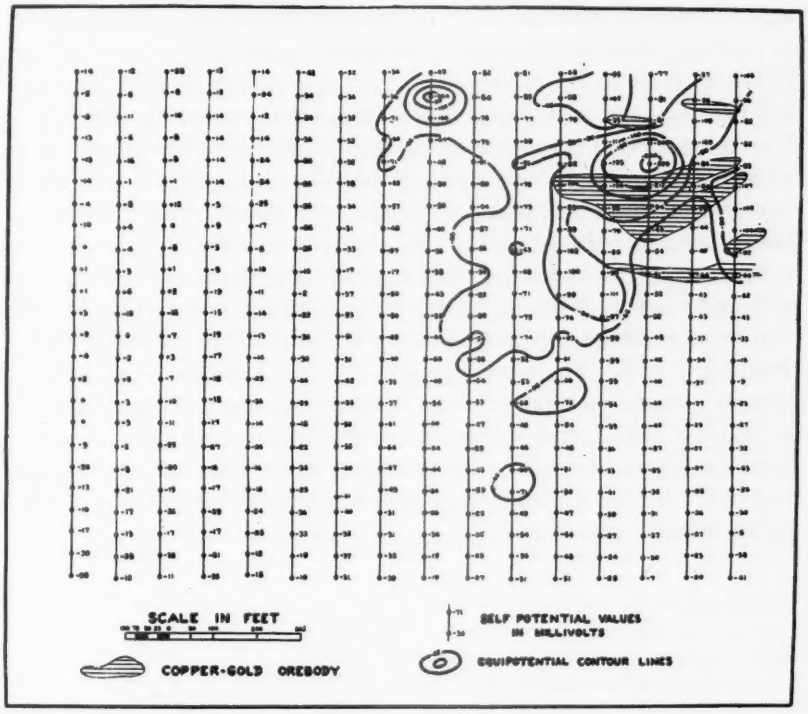

FIG. 6. Drop of natural potential over a sulphide ore body.

sulphide lenses of relatively small extent occur along a gently dipping contact between two lava flows; their development is costly and requires closely spaced vertical drill holes. By simultaneously measuring the resistivity in two neighboring holes, it was found that the presence or absence of sulphides in the vicinity could be suggested and that such electrical logging might eventually result in considerable saving by permitting the drilling of the bore-holes farther apart without affecting ore results.

FUTURE OF GEOPHYSICAL PROSPECTING

The practical value of geophysics in prospecting for gold and base metals in Canada is just beginning to receive the general recognition that it deserves and the Canadian mining industry still falls far behind for instance, the American oil industry as regards the proportion of its revenues that it spends on geophysical prospecting. It is, however, safe to predict a brilliant and fast growing development of geophysics in coming years. Recent, highly successful applications have aroused public interest in the science, and the basic principles by which data are obtained are now being more clearly understood by the mining fraternity, so that from now on, close and effective cooperation can be expected between geologists and geophysicists. Important new methods and instruments, such as the airborne magnetometers, have already been introduced and active research now being conducted by a number of government bodies as well as by private organizations will undoubtedly result in further improvements and techniques that will be of practical application to the Canadian exploration problems. Bearing in mind the undeniable fact that the Pre-Cambrian Shield is almost completely covered with overburden, one cannot escape the conclusion that future exploration will have to be guided to an increasing degree by geophysical indications and that consequently geophysics will play an important part in further development of Canadian mineral resources.

PATENTS*

The Patents below are listed in accordance with the complete classification as published in GEOPHYSICS, April, 1947.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,418,136. W. A. Munson and J. C. Steinberg. Iss. 4/1/47. App. 11/10/43. Assign. Bell Telephone Laboratories, Inc.

Acoustic Range Finder. An acoustic ranging apparatus in which the signals are recorded on magnetic recorders and reproduced and analysed on a c-r tube screen.

U. S. No. 2,418,964. D. L. Arenberg. Iss. 4/15/47. App. 7/9/45. Assign. U. S. A.

Electromechanical Apparatus. A time-delay apparatus for a radar system, the time delay being obtained by passing a supersonic wave down a rod of birefringent material and picking up its arrival at the other end of the rod by a polarized light beam on a photocell with analyser.

U. S. No. 2,419,894. W. W. Hayes. Iss. 4/29/47. App. 8/1/45. Assign. Bendix Aviation Corp.

Acoustic System for Uniform Distribution of Sound. A public address system in which the output from the amplifier is fed into an artificial transmission line along which are connected reproducers placed in various parts of the auditorium.

U. S. No. 2,420,439. M. Morrison. Iss. 5/13/47. App. 11/2/43.

Aircraft Range and Direction Finder. A sonic direction finder having two microphones at the ends of a base line, the electrical signals being separately heterodyned with an oscillator of selected frequency, filtered with narrow band-pass filters and compared in phase with a c-r tube.

U. S. No. 2,422,446. A. A. Stuart, Jr. Iss. 6/17/47. App. 5/15/41. Assign. Bendix Aviation Corp.

Sonic Direction Finding. A sound direction indicator having a directional microphone whose output is amplified and fed to one phase of a two phase motor and a non-directional microphone whose output is amplified and fed to the other phase of the motor and the motor connected to rotate the directional microphone into a null orientation.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. 2,419,046. I. Wolff and R. C. Sanders, Jr. Iss. 4/15/46. App. 5/29/42. Assign. Radio Corp. of America.

Frequency Modulated Altimeter or Distance Indicator. A receiving system for frequency modulated radio distance indicators in which balanced detector tubes are used to eliminate amplitude modulation effects, one tube receiving the reflected signal and the heterodyning signal and the other tube receiving only the heterodyning signal.

U. S. No. 2,420,199. R. C. Sanders, Jr. Iss. 5/6/47. App. 6/4/42. Assign. Radio Corp. of America.

Frequency Modulated Altimeter or Distance Indicator. A frequency modulated radio

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation.

distance indicator in which the reflected signal is applied in parallel to two tubes and the heterodyning signal is applied in push-pull so as to balance out amplitude modulation effects.

U. S. No. 2,420,339. J. Rabinow. Iss. 5/13/47. App. 8/22/44. Assign. U. S. A.

Course-Recording Camera. A fixed camera for recording the course of a moving object and having a rotating shutter at the lens, a focal plane shutter and stadia-type sight through adjustment of which the operator synchronizes the movement of the focal plane shutter with the image.

U. S. No. 2,421,248. L. De Forest. Iss. 5/27/47. App. 5/10/41. Assign. Allen B. DuMont Laboratories, Inc.

Method of and Apparatus for Determining Absolute Altitude. A pulse-echo type of radio altimeter using a spark-gap type directional transmitter and indicating the distance by the sweep of a c-r beam between transmitted and reflected impulses.

U. S. No. 2,421,783. E. D. Glatz. Iss. 6/10/47. App. 3/19/45.

Position Indicator for Aircraft in Flight. An aircraft odometer in which a stylus carried on a motor driven worm traverses a map, the motor speed being controlled by air pressure at the leading edge of the airplane wing.

U. S. No. 2,421,785. J. L. Hathaway. Iss. 6/10/47. App. 2/28/39. Assign. Radio Corp. of America.

Electric Altimeter. An electric altimeter having a wave timing system for measuring high altitudes and a capacity-bridge system for measuring low altitudes and with their indications combined.

U. S. No. 2,422,064. E. I. Anderson and A. Barco. Iss. 6/10/47. App. 10/26/43. Assign. Radio Corp. of America.

Ground Speed Indicator. An airplane ground-speed indicator in which radio waves are transmitted forward and backward from the plane, received after reflection and the frequency difference due to Doppler effect observed by a beat method.

U. S. No. 2,422,079. W. L. Carlson and V. D. Landon. Iss. 6/10/47. App. 11/21/42. Assign. Radio Corp. of America.

Frequency Modulated Altimeter or Distance Indicator. A frequency modulated radio distance indicator in which the reflected signal is applied in parallel opposition to two diodes and mixed with a signal which is half the frequency of the transmitter in order to balance out amplitude-modulation effects.

U. S. No. 2,422,133. R. C. Sanders, Jr. Iss. 6/10/47. App. 12/30/42. Assign. Radio Corp. of America.

Frequency Modulated Altimeter or Distance Indicator. A frequency modulated radio distance indicator having a saw tooth frequency modulation and in which the beat frequency produced by combining the reflected and radiated signals is fed into a regenerative feedback circuit with the proper time delay between cycles to give reinforcement.

U. S. No. 2,423,023. W. D. Hershberger. Iss. 6/24/47. App. 9/30/38. Assign. Radio Corp. of America.

Obstacle Detection by Radio Waves. A radio pulse-echo system for observing velocity and distance of objects by timing the reflection and making a frequency analysis of the reflection on a c-r tube to detect Doppler effects.

U. S. No. 2,423,024. W. D. Hershberger. Iss. 6/24/47. App. 12/26/41. Assign. Radio Corp. of America.

Radio Pulse Altimeter and Object Detector. A combined altimeter and object detecting system in which a pulse for object location is obtained by keying a master oscillator, and a shorter pulse for altitude measurement is obtained by passing the master oscillator pulse through a power amplifier which is keyed on for only a portion of the master-oscillator time.

24—BAROMETER

U. S. No. 2,422,702. C. H. H. Rodanet. Iss. 6/24/47. App. 9/1/39 and 10/22/40. Vested in Attorney General of U. S.

Apparatus for Testing Altimetric Devices. A control system for selectively obtaining subatmospheric pressures in a bell jar and having a mercury column with contacts controlling a vaccuum valve and also an auxiliary vessel and differential pressure valve to control rate of exhaust of the bell jar.

36—BOTTOM HOLE SAMPLER

U. S. No. 2,418,500. L. S. Chambers. Iss. 4/8/47. App. 3/17/42.

Apparatus for Sampling Formation Fluids. A wire-line operated bottom-hole fluid sampler which latches to the drill stem, has a punch which is forced into the formation by weight of the drill pipe, and in which the withdrawing operation pulls a piston up to allow entrance of formation fluid and then unlatches from the drill stem.

48—CASING PERFORATOR

U. S. No. 2,418,486. J. G. Smylie. Iss. 4/8/47. App. 5/6/44.

Gun Perforator. A perforating gun made up of sections screwed together end-to-end with a recessed area at the connection and an annular band of rubber in the recess to seal it from well fluid.

U. S. No. 2,419,841. W. Lampel and R. Hörndlein. Iss. 4/29/47. App. 5/17/39 and 12/18/39. Vested in Attorney General of U. S.

Gun Perforator for Oil Well Casings. An electrically fired perforating gun in which the powder is in a metal container having an internal priming wire which comes out for attaching to the electric conductor wire.

64—COMMUNICATION DEVICE

U. S. No. 2,419,833. H. E. Grimes. Iss. 4/29/47. App. 12/12/45.

Antenna Arrangement for Induction Communication System. A loop system for induction communication systems in which one or more large fixed loops surround parts of a town and small mobile loops are always inside the large loop.

U. S. No. 2,420,868. M. G. Crosby. Iss. 5/20/47. App. 4/22/43. Assign. Radio Corp. of America.

Diversity Combining Circuit. A diversity radio receiving system in which several receivers are used and their outputs combined to reduce the effect of fading, the outputs being fed through diodes to a common resistor which has a positive bias.

68—COMPUTING DEVICES

U. S. No. 3,419,852. J. E. Owen. Iss. 4/29/47. App. 2/19/44. Assign. Geophysical Research Corp.

Apparatus for Measuring the Ratio or Product of Two Alternating Voltages. A network having two controlled bridge-connected triode-rectifier type a-c attenuators whose inputs are connected to the voltages to be divided or multiplied, the d-c output of one attenuator being used to control both attenuators and the output of the other being recorded.

U. S. No. 2,422,240. H. D. Jackes. Iss. 6/17/47. App. 6/23/43. Assign. Wright Aeronautical Corp.

Electrical Ratio Indicating Instrument. An apparatus for indicating the ratio of two quantities and in which each quantity controls the frequency of interruption of d-c in the primary of transformers each of whose secondary pulses are fed to opposed dynamometer coils on a common indicator shaft.

76—CONTINUOUS WAVE SEISMIC TESTING

U. S. No. 2,422,639. H. S. Wenander. Iss. 6/17/47. App. 12/16/44. Assign. Vibro-Plus Corp.

Vibrating Device. A vibrator having a conical pendulum which is rotated inside a cylindrical tube, the pendulum having an eccentric weight which rolls against the wall of the tube.

80—CORE BARREL

U. S. No. 2,419,738. L. F. Smith. Iss. 4/29/47. App. 6/23/44.

Drill Rod. A drill rod having an inner and an outer sleeve, the fluid being pumped down in an annular space between the two and up through the center one, so that cores and cuttings will be carried to the surface.

U. S. No. 2,421,997. W. S. Crake. Iss. 6/10/47. App. 6/21/45. Assign. Shell Development Co.

Core Barrel. A coring tool which cuts a core of small diameter and catches the broken core fragments in a trap of larger diameter contained inside the core barrel.

U. S. No. 2,422,955. C. F. Duffield. Iss. 6/24/47. App. 8/16/43 and 7/18/44.

Core Recovering Device. A core barrel in which the core tube actuates a wedge shaped core grip when the desired length of core has been cut.

92—DRILL

U. S. No. 2,418,601. D. Richards. Iss. 4/8/47. App. 1/19/44. Assign. The Buda Co.

Earth Drill. An auger type of drill mounted on a trailer or truck and having a tower which can be lowered.

U. S. No. 2,419,738. L. F. Smith. Iss. 4/29/47. App. 6/23/44.

Drill Rod. A drill rod having an inner and an outer sleeve, the fluid being pumped down in an annular space between the two and up through the center one, so that cores and cuttings will be carried to the surface.

104—EARTH AUGER

U. S. No. 2,421,970. T. C. Smith. Iss. 6/10/47. App. 7/11/44. Assign. American Telephone and Telegraph Co.

Earth Boring Machine. A motor driven earth auger mounted on a vehicle and arranged so that when the auger is raised to the limit of its upward travel it engages the spinning gears and throws off the dirt.

108—ECHO SOUNDING

U. S. No. 2,418,156. J. H. Bollman. Iss. 4/1/47. App. 4/15/43. Assign. Bell Telephone Laboratories, Inc.

Direction Finding System. A pulse-echo direction finding system in which three beams differing slightly in frequency and direction are transmitted and the reflected signal is demodulated and converted into a low frequency whose phase is indicated on a non-restoring meter.

116—ELECTRIC LOGGING

U. S. No. 2,419,852. J. E. Owen. Iss. 4/29/47. App. 2/19/44. Assign. Geophysical Research Corp.

Apparatus for Measuring the Ratio or Product of Two Alternating Voltages. A network having two controlled bridge-connected triode-rectifier type a-c attenuators whose inputs are connected to the voltages to be divided or multiplied, the d-c output of one attenuator being used to control both attenuators and the output of the other being recorded.

132—ELECTROMAGNETIC PROSPECTING

U. S. No. 2,419,833. H. E. Grimes. Iss. 4/29/47. App. 12/12/45.

Antenna Arrangement for Induction Communication System. A loop system for induction communication systems in which one or more large fixed loops surround parts of a town and small mobile loops are always inside the large loop.

136—EXPLOSIVE

U. S. No. 2,420,182. O. W. Lundblad. Iss. 5/6/47. App. 1/24/46. Assign. Hercules Powder Co.

Lowering Device. A device for lowering explosive cartridges into a shot hole and

having a hook which engages a cord fastened to the cartridge and a knife which cuts the cord when the device is given a sudden upward jerk.

U. S. No. 2,420,651. L. A. Burrows, G. H. Loving, R. W. Nydegger and G. H. Smith. Iss. 5/20/47. App. 12/9/42. Assign. E. I. du Pont de Nemours & Co.

Ignition Device. A pull-wire igniter for torpedo caps which is waterproof and unaffected by temperature and has a rubber plug at the top of the cap through which the wire passes.

140—FLAW DETECTOR

U. S. No. 2,420,646. R. Bloom, Jr., E. N. Klemgard, B. Ronay and R. W. Miller. Iss. 5/20/47. App. 1/25/45.

Method of Detecting Flaws in Metal Articles. A method of detecting surface flaws by applying to the surface an oil containing a dissolved dye, then wiping off excess solution, and applying a finely divided absorbent material such as diatomaceous earth.

U. S. No. 2,418,686. T. Zuschlag. Iss. 4/8/47. App. 1/13/44. Assign. Magnetic Analysis Corp.

Testing of Magnetic Materials. A magnetic inspection method in which the material being inspected and a known sample are passed through coils excited by a-c and the difference between the emfs induced in adjacent secondary coils is indicated.

148—FLOW METER

U. S. No. 2,418,876. E. J. Grace, Jr. Iss. 4/15/47. App. 10/6/44. Assign. Sun Oil Co.

Apparatus for Collecting Fluid Samples. An apparatus for obtaining from a flow line an average sample of fluid in which repeated small samples are taken at a frequency proportional to the indications of an integrating flow meter.

U. S. No. 2,422,762. H. A. Williams. Iss. 6/24/47. App. 10/12/43. Assign. Bendix Aviation Corp.

Remote Indicating Flowmeter. A deflecting vane type of flowmeter in which the vane carries a permanent magnet whose deflection is picked up by an external annular a-c excited stator core and reproduced on a similar repeater.

152—FLUORESCENCE LOGGING

Co. *U. S. No. 2,422,852.* G. L. Ratcliffe. Iss. 6/24/47. App. 7/11/42. Assign. National Lead Co.

Process of Detecting Oil Dispersed in Well Drilling Fluids. A method of mud logging in which the mud coming out of the hole contacts a paper record strip which absorbs the oil and which is moved in proportion to depth.

180—GRAVIMETER

U. S. No. 2,418,786. F. H. Nadig and J. L. Bohn. Iss. 4/8/47. App. 10/16/43.

Hydraulic Interferometer. An interferometer for measuring small motions in which the motion actuates a hydraulic plunger and is hydraulically transmitted to the moving mirror of the interferometer.

188—HYGROMETER

U. S. No. 2,422,742. P. H. Odessey. Iss. 6/24/47. App. 3/5/42. Assign. Portable Products Corp.

Meter for Measuring Moisture Content. A moisture meter for hygroscopic materials in which the material is placed between the plates of a condenser connected in a variable frequency oscillator circuit and the capacity change determined by comparison with a standard-frequency oscillator.

224—MAGNETIC RECORDER

U. S. No. 2,418,541, M. Camras. Iss. 4/8/47. App. 11/22/43. Assign. Armour Research Foundation.

Reversible Drive for a Magnetic Recording Medium. An electric motor driven magnetic recorder in which the motor is selectively connected to either reel by a friction drive.

U. S. No. 2,418,542. M. Camras. Iss. 4/8/47. App. 1/20/44. Assign. Armour Research Foundation.

Magnetizing and Erasing Head Arrangement for Magnetic Recorders. A combined erasing and recording head for a magnetic recorder using a single core with coils arranged so that stray field from the a-c erasing part provides a high frequency flux component in the recording part.

U. S. No. 2,418,543. M. Camras. Iss. 4/8/47. App. 3/29/44. Assign. Armour Research Foundation.

Magnetic Recording or Reproducing Device. A magnetic recorder in which the recording head bears against the outside of a drive pulley on which the tape runs.

U. S. No. 2,419,195. S. J. Begun. Iss. 4/22/47. App. 6/16/44. Assign. The Brush Development Co.

Apparatus and Method for Magnetic Recording. A magnetic recording system in which a modulated carrier is recorded.

U. S. No. 2,419,476. S. J. Begun. Iss. 4/22/47. App. 1/31/46. Assign. Magnetone, Inc.

Winding Control Means for Magnetic Recording and Reproducing Apparatus. A magnetic recorder which has a device for spirally winding the wire on spools and has a brake on the trailing reel which is actuated upon stopping of the driving reel.

U. S. No. 2,420,671. J. B. Little. Iss. 5/20/47. App. 10/27/41. Assign. Bell Telephone Laboratories, Inc.

Magnetic Recorder. A magnetic tape recorder having an oscillating distributing mechanism which winds the tape on the receiving spool in a spiral.

228—MAGNETIC TESTING

U. S. No. 2,418,686. T. Zuschlag. Iss. 4/8/47. App. 1/13/44. Assign. Magnetic Analysis Corp.

Testing of Magnetic Materials. A magnetic-inspection method in which the material

being inspected and a known sample are passed through coils excited by a-c, and the difference between the emfs induced in adjacent secondary coils is indicated.

U. S. No. 2,419,591. C. J. Quigley. Iss. 4/29/47. App. 11/5/43.

Magnetic Minesweeping Electrode Cable. A combined electrode and cable for underwater magnetic minesweeping which is made of inner strands of copper wire covered with an electrically conductive corrosion resisting coating of graphite and plastic and with the outer strands of steel wire.

U. S. No. 2,421,583. A. A. Stuart, Jr. Iss. 6/3/47. App. 9/2/44. Assign. Bendix Aviation Corp.

Degaussing System. A degaussing current-control system having a flux-gate detecting element whose output controls the generator output.

U. S. No. 2,421,775. F. B. Doane. Iss. 6/10/47. App. 6/28/43. Assign. Magnaflux Corp.

Method and Apparatus for Magnetic Testing. A method of making a universal magnetic-particle inspection by applying a fluctuating magnetizing force in one direction and simultaneously applying a fluctuating magnetizing force in another direction.

232—MAGNETOMETER

U. S. No. 2,418,553. E. M. Irwin. Iss. 4/8/47. App. 8/3/43.

Flux Measuring System. A flux measuring device having a T-shaped core which is excited by a.c. in a coil around the leg of the T and having secondary coils on the two arms connected in opposition to a meter.

U. S. No. 2,420,580. L. L. Antes. Iss. 5/13/47. App. 6/15/42. Assign. Standard Oil Development Co.

Magnetometer. A vertical-component magnetometer in which a coil on a gimbal mounting held in a vertical plane by gravity is supplied with a-c, the mechanical vibration detected with a piezo crystal and the current in Helmholz coils adjusted until a minimum vibration is observed.

236—MASS SPECTROMETRY

U. S. No. 2,422,264. R. V. Seaman. Iss. 6/17/47. App. 5/8/45.

Differential Ionic Analyser. An ionic analyser having an ionization chamber which leads to a Y-tube one of whose branches is at high negative potential and the other at a high positive potential and the end of each branch tube having an ion target which may be observed spectroscopically.

244—MICROPHONE

U. S. No. 2,418,132. J. P. Maxfield. Iss. 4/1/47. App. 4/12/44. Assign. Bell Telephone Laboratories, Inc.

Electromechanical Signal Translating Device. A low-frequency microphone having a diaphragm to which magnetostrictive elements are mechanically connected in push-pull and a high frequency magnetic circuit for energizing the elements in parallel, the elements having their coils connected in opposition.

U. S. No. 2,420,737. J. de Boer. Iss. 5/20/47. App. 11/11/39 and 3/23/43. Assign. Hartford National Bank and Trust Co.

Granulated Carbon Microphone. An inertia-type throat microphone having a lead mass fastened to the center of a diaphragm, the carbon granule recess having a thickness about ten times the maximum amplitude of the diaphragm.

U. S. No. 2,421,820. R. Vermeulen. Iss. 6/10/47. App. 3/7/41 and 3/23/43. Assign. Hartford National Bank and Trust Co.

Microphone. A microphone for use in locations of high noise level and made up of a number of pressure gradient microphone elements connected together and directed outward from a cavity so that extraneous noise cancels, but sound directed into the cavity gives a response.

252—MUD LOGGING

U. S. No. 2,422,852. G. L. Ratcliffe. Iss. 6/24/47. App. 7/11/42. Assign. National Lead Co.

Process of Detecting Oil Dispersed in Well Drilling Fluids. A method of mud logging in which the mud coming out of the hole contacts a paper record strip which absorbs the oil and which is moved in proportion to depth.

288—PRESSURE GAUGE

U. S. No. 2,419,061. A. H. Emery. Iss. 5/15/47. App. 9/22/44. Assign. The Baldwin Locomotive Works.

Pressure Operated Electric Strain Gage. A pressure gage having a bellows which acts to separate the legs of a U-shaped strip with a filament-type strain gage mounted on the bend of the U.

U. S. No. 2,420,148. R. H. Ostergren. Iss. 5/6/47. App. 11/8/43. Assign. Douglas Aircraft Co., Inc.

Pressure Indicator. A remote indicating pressure gauge having filament-type strain gauges mounted on a piece of thin walled tubing or tubing which is flattened.

U. S. No. 2,421,907. W. R. Postlewaite. Iss. 6/10/47. App. 12/26/44. Assign. California Research Corp.

Well Pressure Gauge. A remote indicating electric bottom-hole pressure gauge using a filament-type strain gauge wound on an evacuated cylinder the outside of which is exposed to well pressure.

312—RADIO NAVIGATION

U. S. No. 2,419,970. R. B. Roe and J. B. Gray. Iss. 5/6/47. App. 5/29/43. Assign. Sperry Gyroscope Co., Inc.

Navigation System. A radio navigation system in which the craft follows a homing course and in which the steering effect of a change in bearing to the transmitting station is decreased as the intensity of the received signal increases.

U. S. No. 2,420,016. R. C. Sanders, Jr. Iss. 5/6/47. App. 5/23/44. Assign. Radio Corp. of America.

Reflected Wave Navigation Device. A variable-frequency radar navigation device for a target seeking craft in which the steering effect is a varying multiple of the observed change in azimuth of the target, and this multiple is reduced in direct proportion to the distance from the target.

U. S. No. 2,420,017. R. C. Sanders. Jr. Iss. 5/6/47. App. 5/23/44. Assign. Radio Corp. of America.

Reflected Wave Navigation Device. A variable-frequency radar navigation device for a target seeking craft in which the steering effect is a varying multiple of the observed change in azimuth of the target, and this multiple is reduced in direct proportion to the predicted time for the craft to reach the target.

U. S. No. 2,422,100. H. S. Huff. Iss. 6/10/47. App. 1/6/43. Assign. Radio Corp. of America.

Position Determining System. A radio navigation system based on differences in wave propagation time from three fixed stations and in which the distances are indicated by three circular traces on a three gun c-r tube.

316—RADIO RANGING

U. S. No. 2,418,156. J. H. Bollman. Iss. 4/1/47. App. 4/15/34. Assign. Bell Telephone Laboratories, Inc.

Direction Finding System. A pulse-echo direction finding system in which three beams differing slightly in frequency and direction are transmitted and the reflected signal is demodulated and converted into a low frequency whose phase is indicated on a non-restoring meter.

U. S. No. 2,418,308. D. G. C. Luck. Iss. 4/1/47. App. 6/27/42. Assign. Radio Corp. of America.

Radio Direction Finder. A radio direction finding system using four antennas at the corners of a square with a non-directional antenna at the center, the signals from opposite corners being fed in opposition to balanced modulators and combined with the non-directional antenna signal to give a bearing and elevation indication on two meters.

U. S. No. 2,419,590. A. Preisman. Iss. 4/29/47. App. 2/27/43. Assign. Federal Telephone and Radio Corp.

Pulse Echo System. A radio pulse-echo system in which a variable-width comparison pulse is generated and fed into the c-r tube so that it may be used to measure reflection time.

U. S. No. 2,419,987. W. I . Carlson. Iss. 5/6/47. App. 7/30/42. Assign. Radio Corp. of America.

Direction Finder. A radio direction finder using a non-directive antenna and a directive loop, the tuning in the latter circuit being varied by a saturable reactor energized by an audio oscillator, and with the output of the loop circuit combined with that of the antenna, demodulated and fed to a left-right indicator whose field coil is energized by the audio oscillator.

U. S. No. 2,419,994. C. W. Hansell. Iss. 5/6/47. App. 8/1/42. Assign. Radio Corp. of America.

Direction Finding. A radio direction finder using two directional antennas with overlapping patterns and different heterodyne oscillators and feeding an amplitude limiter, a wave-length modulation detector and reverse-current output indicator.

U. S. No. 2,420,395. G. B. Greene. Iss. 5/13/47. App. 4/10/42. Assign. L. M. Harvey.

Radio Direction Finding Circuit. A radio direction finding circuit using a non-directional antenna and a loop, the signal from the loop being fed through a delayed avc circuit before combining with the antenna signal so that high sensitivity is obtained near the null position without overloading at positions away from null.

U. S. No. 2,421,009. H. G. Busignies and A. G. Richardson. Iss. 5/27/47. App. 4/23/42. Assign. Federal Telephone and Radio Corp.

Direction Finding System. A radio direction finding system using a directive array of remotely located dipoles feeding three transmission lines through coupling amplifiers which are remotely controlled.

U. S. No. 2,421,028. A. P. King. Iss. 5/27/47. App. 11/24/42. Assign. Bell Telephone Laboratories, Inc.

Wave Reflection Aircraft Detector Using Rotating Polarization. A radar aircraft detecting system in which the dipole antenna and its reflector are rotated about the direction of radiation to eliminate fading effect as the aircraft changes its reflection angle.

U. S. No. 2,421,394. J. C. Schelleng. Iss. 6/3/47. App. 6/10/42. Assign. Bell Telephone Laboratories, Inc.

Distance Measuring System. A system for measuring the distance between a moving station and a relay station in which the Doppler effect is eliminated and the frequency of the transmitted wave varied over a predetermined range and the number of beats between the transmitted and received waves counted.

U. S. No. 2,422,134. R. C. Sanders, Jr. Iss. 6/10/47. App. 3/29/43. Assign. Radio Corp. of America.

Distance Indicator. A frequency-modulated radio distance indicator in which the beat frequency produced by combining the reflected and radiated signals is applied to a multiple tuned reed frequency meter so that several reflectors may be indicated.

U. S. No. 2,422,135. R. C. Sanders, Jr. Iss. 6/10/47. App. 6/26/43. Assign. Radio Corp. of America.

Frequency Modulated Distance Indicator. A frequency modulated radio distance indicator for detecting low flying aircraft and which has a saw-tooth frequency modulation with the beat frequency produced by combining the reflected and radiated signals fed into a regenerative feedback circuit with the proper time delay to give cancellation so as to eliminate indications produced from stationary objects.

U. S. No. 2,422,157. I. Wolfe. Iss. 6/10/47. App. 7/31/42. Assign. Radio Corp. of America.

Distance Measuring Apparatus. A frequency-modulated radio distance indicator

for indicating distance to several reflectors and which has a cyclical frequency modulation of variable rate, and in which the beat frequency produced by combining the reflected and radiated signals is fed through a tuned amplifier to a neon lamp rotated behind a scale at a rate synchronous with the frequency modulation cycle.

U. S. No. 2,422,295. T. T. Eaton. Iss. 6/17/47. App. 8/30/43. Assign. Radio Corp. of America.

Recorder for Radio Locators. An indicator for a radio pulse-echo object locator in which the c-r tube screen is projected onto an iconoscope tube and recorded on a facsimile recorder.

U. S. No. 2,422,382. H. T. Winchel. Iss. 6/17/47. App. 3/29/43. Assign. Bendix Aviation Corp.

Distance Measuring Apparatus. A radio pulse-echo system using a superregenerative circuit both as transmitter and receiver.

U. S. No. 2,422,654. E. Bruce. Iss. 6/24/47. App. 8/19/43. Assign. Bell Telephone Laboratories, Inc.,

Time Measuring System. A system for measuring reflection time of a radio pulse using an R-C timing circuit.

U. S. No. 2,422,655. G. Hecht. Iss. 6/24/47. App. 9/16/43. Assign. Bell Telephone Laboratories, Inc.

Time Measuring System. A system for measuring reflection time of a radio pulse using an R-C timing circuit with a potentiometer tapped to select a comparison voltage.

U. S. No. 2,422,696. L. A. Meacham. Iss. 6/24/47. App. 11/15/44. Assign. Bell Telephone Laboratories, Inc.

Timing Circuit. A system for measuring the reflection time of a radio pulse which uses one timing circuit on the control grid of the timing tube and a second timing circuit on the screen grid of the tube so as to operate the timing tube at constant grid-to-screen potential difference.

U. S. No. 2,422,697. L. A. Meacham. Iss. 6/24/47. App. 11/15/44. Assign. Bell Telephone Laboratories, Inc.

Viewing System. A radar indicating system having a c-r tube plan-position indicator and an auxiliary c-r tube which gives a magnified picture of a small selected area.

U. S. No. 2,423,064. C. W. Earp, I. R. J. James and R. F. Cleaver. Iss. 6/24/47. App. 2/9/40 and 11/23/42. Assign. Standard Telephones and Cables Ltd.

Radio Direction Finding Equipment. A system for operating two sets of direction finding equipment from the same antennas in which the antennas are connected in bridge circuits with balancing impedances and connections taken off from the two diagonals of the bridges.

324—RECORDER

U. S. No. 2,419,641. G. T. Hart, Jr. Iss. 4/29/47. App. 2/22/44. Assign. United Shoe Machinery Corp.

Photoelectric Line-Following Apparatus. A curve-tracking device having two photocells which view small triangular areas on each side of the curve and also having a photoelectric pilot cell which tracks slightly ahead and reduces the tracking speed when abrupt changes in the curve occur.

U. S. No. 2,419,682. V. Guillemin, Jr. Iss. 4/29/47. App. 2/11/42.

Electrocardiotachometer. A chronograph for recording the occurrence of heart beats and using an electrocardiac amplifier which trips a trigger tube to actuate a recording pen at each beat.

U. S. No. 2,422,140. C. M. Sinnett. Iss. 6/10/47. App. 5/15/43. Assign. Radio Corp. of America.

Frequency Modulated Recording and Reproducing System. A home recording system using a paper tape on which frequency modulated signals are embossed by a stylus, reproduction being by means of a stylus and roller acting as a variable capacity condenser.

U. S. No. 2,422,143. R. M. Somers and R. C. Van Camp. Iss. 6/10/47. App. 1/31/44. Assign. Thomas A. Edison, Inc.

Magazine Type Magnetic Recorder and Reproducer. A magnetic recorder cabinet having the wire and its drive mechanism mounted in a drawer and the motor mounted in the cabinet, and with a latch on the drawer which disengages the driving motor when released to remove the drawer.

356—SEISMOGRAPH MIXING

U. S. No. 2,420,868. M. G. Crosby. Iss. 5/20/47. App. 4/22/43. Assign. Radio Corp. of America.

Diversity Combining Circuit. A diversity radio receiving system in which several receivers are used and their outputs combined to reduce the effect of fading, the outputs being fed through diodes to a common resistor which has a positive bias.

364—SEISMOGRAPH RECORDER

U. S. No. 2,420,025. W. W. Young. Iss. 5/6/47. App. 11/30/45. Assign. Sun Oil Co.

Vibration Recorder. A system for obtaining a blank space for an identification stamp at the beginning of a seismograph record in which relays turn off the recording lights when the camera is started and the lights are turned on again by the blasting machine before firing.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,420,571. E. J. Shimek and G. M. Groenendyke. Iss. 5/13/47. App. 6/7/44. Assign. Socony-Vacuum Oil Co., Inc.

Gain-Controlling System for Seismographs. An expander for seismograph amplifiers in which the initial gain, final gain and time rate of gain may be independently adjusted.

U. S. No. 2,420,672. R. Maillet. Iss. 5/20/47. App. 1/5/39 and 2/4/39. Vested in Attorney General of U. S.

Geophysical Prospecting. Apparatus for obtaining time control of sensitivity and/or

filter cut-off frequency by clutching in a motor-driven variable condenser or cam-operated rheostat at the firing instant.

376—SEISMOMETER

U. S. No. 2,418,953. R. W. Raitt. Iss. 4/15/47. App. 2/25/41. Assign. Geophysical Engineering Corp.

Transducing System. A variable air-gap reluctance type seismometer in which the ratio of magnetic to mechanical stiffness is about four fifths so as to obtain electromagnetic damping without introducing instability.

412—SPECIFIC GRAVITY MEASUREMENTS

U. S. No. 2,418,592. J. F. Maienshein. Iss. 4/8/47. App. 8/3/44. Assign. The Brown Instrument Co.

Liquid Density Measuring Apparatus. A system for continuously measuring the specific gravity of a liquid which has an open jar which is partially filled with mercury floating on the surface of the liquid in a constant level tank, and which records the back pressure of air bubbling out of a fixed tube extending into the mercury.

416—SPECTROGRAPH

U. S. No. 2,420,077. M. F. Hassler and R. W. Lindhurst. Iss. 5/6/47. App. 1/24/44.

Direct Reading Spectrochemical Analysis Apparatus. A grating spectrometer using photoelectric light receivers which may distinguish close spectral lines by having narrow mirrors of unequal distances from the grating which reflect the lines into the photo cells.

428—STRAIN GAUGE

U. S. No. 2,419,061. A. H. Emery. Iss. 4/15/47. App. 9/22/44. Assign. The Baldwin Locomotive Works.

Pressure Operated Electric Strain Gage. A pressure gage having a bellows which acts to separate the legs of a U-shaped strip with a filament-type strain gage mounted on the bend of the U.

U. S. No. 2,420,148. R. H. Ostergren. Iss. 5/6/47. App. 11/8/43. Assign. Douglas Aircraft Co., Inc.

Pressure Indicator. A remote indicating pressure gauge having filament-type strain gauges mounted on a piece of thin-walled tubing or tubing which is flattened.

U. S. No. 2,421,420. C. M. Hathaway. Iss. 6/3/47. App. 11/8/43. Assign. Hathaway Instrument Co.

Electrical Gaging Apparatus. A variable impedance bridge-type strain gauge whose unbalance is detected by two bridge-type rectifiers having a balanced circulating current for operation at maximum sensitivity.

U. S. No. 2,422,806. D. Silverman and T. Gilmartin. Iss. 6/24/47. App. 4/28/44. Assign. Stanolind Oil and Gas Co.

Drill Bit Pressure Gauge. A system for measuring drill-bit pressure by having a

modulated carrier-type strain gauge on a collar just above the drill and transmitting the signals to the surface.

436—SUBMARINE SIGNALING

U. S. No. 2,418,846. L. A. Meacham. Iss. 4/15/47. App. 12/3/43. Assign. Bell Telephone Laboratories, Inc.

Submarine Detection System. An ultrasonic submarine-detecting system in which a slowly rotating directional transmitter and a swiftly rotating directional receiver are mounted in a submerged trailer and connected by an electric cable to a c-r tube having synchronous scanning.

U. S. No. 2,419,196. H. Benioff. Iss. 4/22/47. App. 5/3/40. Assign. Submarine Signal Co.

Electro acoustic Transducer. An electromagnetic hydrophone in which the radiating plate has ribs with opposing magnetized reeds which are set into resonant vibration by the current in a fixed coil.

U. S. No. 2,419,197. H. Benioff. Iss. 4/22/47. App. 5/3/40. Assign. Submarine Signal Co.

Electro acoustic Transducer. A piezoelectric hydrophone in which the radiating plate has ribs with opposing reeds to which Rochelle salt crystals are cemented.

U. S. No. 2,419,603. E. W. Smith. Iss. 4/29/47. App. 8/15/35. Assign. Submarine Signa Co.

Apparatus for Submarine Signaling. A mounting for an underwater sender or receiver on a ship in which the orientation of the device may be remotely controlled by the operator or held horizontal by a pendulum.

U. S. No. 2,419.608. E. E. Turner, Jr. Iss. 4/29/47. App. 5/29/35. Assign. Submarine Signal Co.

Electrical Oscillator. An electromagnetic supersonic oscillator in which the radiating plate carries concentric rings on its back surface, the rings being in a magnetic field structure and having coils which induce a driving current in the rings, and the rings being of such length as to have a vibration node near the radiating plate.

U. S. No. 2,420,676. R. E. Peterson. Iss. 5/20/47. App. 1/23/43 and 12/13/43. Assign. Submarine Signal Co.

Submarine Signaling Apparatus. A directional sound receiver having a sound lens and a rectangular array of pickups at the focal surface of the lens, the pickups being grouped in quadrants so that they may be used to orient the device or the vessel on which it is mounted.

U. S. No. 2,421,263. P. J. Herbst. Iss. 5/27/47. App. 1/3/40. Assign. Radio Corp. of America.

Magnetostrictive Electroacoustic Transducer. A magnetostrictive oscillator having a number of magnetostrictive driving elements whose polarizing field is supplied by permanent magnets supporting the backing plate.

440—SURFACE TESTING

U. S. No. 2,421,578. R. E. Reason. Iss. 6/3/47. App. 6/17/43 and 10/10/44. Assign. Taylor, Taylor & Hobson, Ltd.

Apparatus for Measuring the Degree of Roughness of Surfaces. An electrical surface-roughness tester in which a stylus is drawn over the surface and vertical movements detected and which has filters in the amplifying circuit to permit distinguishing roughness from waviness.

444—SURVEYING APPARATUS

U. S. No. 2,421,628. C. D. Lake and G. F. Daly. Iss. 6/3/47. App. 4/2/43. Assign. International Business Machines Corp.

Odograph. A vehicular odograph in which ratchet pawls move ratchet wheels on the indicator-driving shafts and a photoelectric compass-sensing mechanism controls the position of shields on the ratchet wheels so as to control the progression produced by the pawl.

468—TIME INTERVAL METER

U. S. No. 2,418,964. D. L. Arenberg. Iss. 4/15/47. App. 7/9/45. Assign. U. S. A.

Electromechanical Apparatus. A time-delay apparatus for a radar system, the time delay being obtained by passing a supersonic wave down a rod of birefringent material and picking up its arrival at the other end of the rod by a polarized light beam on a photocell with analyser.

U. S. No. 2,419,576. M. M. Levy. Iss. 4/29/47. App. 1/24/41 and 9/11/42. Assign. Standard Telephones and Cables Ltd.

Apparatus for Measuring Short Time Intervals. Apparatus for measuring a pulse-echo time interval by superimposing on a c-r tube trace an impulse occurring at a known time and the impulse of unknown time and adjusting the known time interval for coincidence.

U. S. No. 2,422,654. E. Bruce. Iss. 6/24/47. App. 8/19/42. Assign. Bell Telephone Laboratories, Inc.

Time Measuring System. A system for measuring reflection time of a radio pulse using an R-C timing circuit.

U. S. No. 2,422,655. G. Hecht. Iss. 6/24/47. App. 9/16/43. Assign. Bell Telephone Laboratories, Inc.

Time Measuring System. A system for measuring reflection time of a radio pulse using an R-C timing circuit with a potentiometer tapped to select a comparison voltage.

U. S. No. 2,422,696. L. A. Meacham Iss. 6/24/47. App. 11/15/44. Assign. Bell Telephone Laboratories, Inc.

Timing Circuit. A system for measuring the reflection time of a radio pulse which uses one timing circuit on the control grid of the timing tube and a second timing circuit on the screen grid of the tube so as to operate the timing tube at constant grid-to-screen potential difference.

U. S. No. 2,422,698. O. R. Miller. Iss. 6/24/47. App. 11/5/42. Assign. Bell Telephone Laboratories, Inc.

Time Measuring System. A time-interval meter using a standard frequency and having cascaded pulse counters which will transmit one pulse for every ten pulses received.

484—TRANSDUCER

U. S. No. 2,419,196. H. Benioff. Iss. 4/22/47. App. 5/3/40. Assign. Submarine Signal Co.

Electro acoustic Transducer. An electromagnetic hydrophone in which the radiating plate has ribs with opposing magnetized reeds which are set into resonant vibration by the current in a fixed coil.

U. S. No. 2,419,197. H. Benioff. Iss. 4/22/47. App. 5/3/40. Assign. Submarine Signal Co.

Electro acoustic Transducer. A piezoelectric hydrophone in which the radiating plate has ribs with opposing reeds to which Rochelle salt crystals are cemented.

U. S. No. 2,421,263. P. J. Herbst. Iss. 5/27/47. App. 1/3/40. Assign. Radio Corp. of America.

Magnetostrictive Electro acoustic Transducer. A magnetostrictive oscillator having a number of magnetostrictive driving elements whose polarizing field is supplied by permanent magnets supporting the backing plate.

U. S. No. 2,421,586. R. W. Tibbetts. Iss. 6/3/47. App. 9/20/44. Assign. Tibbetts Laboratories, Inc.

Piezoelectric Device. A square piezoelectric crystal cut so that it expands along one diagonal and contracts along the other and with flexible toggles connecting the opposite corners, the toggles being connected together and to a load by means of a rod passing through a hole in the center of the crystal.

U. S. No. 2,421,933. H. E. Goldstine. Iss. 6/10/47. App. 5/3/43. Assign. Radio Corp. of America.

Dimension Measuring Device. A dimension comparator in which the length of a concentric transmission line or one dimension of a cavity resonator connected to an ultra-high frequency generator is used to indicate changes in dimension by variations in beat frequency.

U. S. No. 2,422,707. E. E. Turner, Jr. Iss. 6/24/47. App. 7/29/42. Assign. Submarine Signal Co.

Compressional Wave Transmitting or Receiving Device. A cylindrical hydrophone in which electromagnetically induced longitudinal vibrations of a copper tube are coupled at the mid-point node to cause radial vibrations of an outer steel cylinder.

U. S. No. 2,422,817. D. J. Baker. Iss. 6/24/47. App. 3/12/45.

Pickup Head. A phonograph pickup in which the needle flexes a thin magnetic vane carrying a coil in the air gap of a permanent magnet.

500—VOLTMETER

U. S. No. 2,422,766. D. F. Alexander. Iss. 6/24/47. App. 11/30/42. Assign. General Motors Corp.

Peak Transient Meter. A peak transient voltmeter in which peaks above a calibrated level are detected by an electric-eye tube.

516—WELL SIGNALING

U. S. No. 2,421,423. S. Krasnow. Iss. 6/3/47. App. 10/29/36 and 2/15/43. Assign. Geophysical Development Corp.

Method and Apparatus for Taking Physical Measurements in Boreholes. Well logging or testing apparatus in which the measured parameter changes the frequency or modulation of an oscillator driving an acoustic vibrator in the well and the sound is picked up at the surface.

U. S. No. 2,422,806. D. Silverman and T. Gilmartin. Iss. 6/24/47. App. 4/28/44. Assign. Stanolind Oil and Gas Co.

Drill Bit Pressure Gauge. A system for measuring drill-bit pressure by having a modulated carrier-type strain gauge on a collar just above the drill and transmitting the signals to the surface.

520—WELL SURVEYING

U. S. No. 2,419,468. G. A. Smith. Iss. 4/22/47. App. 10/8/41. Assign. Sperry-Sun Well Surveying Co.

Apparatus for Orienting Drill Stems. An apparatus for determining the orientation of drilling tools having two normally concentric pendulums the center one being nonmagnetic and recording inclination and the outer one being magnetic and attracted to one side by a magnet in the drill tool to record its azimuth.

REVIEWS

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GEOPHYSICAL WORK IN SOUTH AFRICA*

By B. D. Maree†

ABSTRACT

The past and present status of geophysical prospecting in the Union of South Africa is briefly reviewed. This is followed by a classified bibliography for this field.

The gravimetric and magnetic methods are mostly used in the Union of South Africa. These methods proved of use in locating and tracing the auriferous and other metalliferous strata under cover and have been very successful. The electrical resistivity and electro-magnetic methods, using instruments designed in South Africa for our conditions, have been extensively used for investigations on underground water and some mineral deposits. The seismic method has been used by one mining company and the Government Geological Survey, but only for experimental surveys; no seismic work has been done since about 1937.

There are the following instruments in use in the Union, about half of them by the Geophysical Branch of the Geological Survey:

about 8 gravimeters,
20–30 magnetometers,
about 10 electrical resistivity instruments,
1 electro-magnetic instrument.

Here there are about 15 experienced and qualified geophysicists engaged in the work with perhaps double as many field assistants. The private companies engaged in exploratory geophysics are usually associated with the gold mining companies and their activities are limited almost solely to the gold exploration. The government keeps a strong

* Manuscript received by Editor June 2, 1947. Bibliographic Survey No. 1, under the auspices of the Special Reviews Committee. One of the purposes of this committee is to sponsor survey articles of particular fields of applied geophysics, based on all published literature of importance and containing a complete bibliography. The Committee will welcome information as to cases in which someone has been surveying or concentrating in a special field and for which permission for publication could be obtained.—Editor.

† Geological Survey. Pretoria, Union of South Africa.

geophysical branch which is engaged in research work and surveys on base minerals, construction problems and underground water.

Lately the private companies were engaged in gravimetric and magnetic surveys in the Orange Free State and Transvaal provinces in search of gold-bearing formations. The Geological Survey is doing much work on underground water, tin fields and radioactive minerals. During the war the government investigated a large area in the Cape province for its possibility of containing natural oil by means mainly of a gravimetric survey. A regional gravimetric survey to cover ultimately the whole Union is also progressing. Reports on these two gravimetric surveys will be forthcoming shortly.

Mainly due to the virtual absence of post-Triassic formations, and since most deposits of economical importance occur in pre-Cambrian formations, the geophysical problems encountered in the Union differ vastly from those in other parts of the world, hence much research was, and still is necessary to develop techniques of approach and the applicable methods and most suitable instruments. Due to the interference of the war, and the confidential nature of most of the surveys, very little has been published lately, but I expect that more papers of a geophysical nature will be published in the future.

Papers *G*-2, 3, and 5 (5 still in press when this review was written) have some special interest at the moment because they show how the Odendaalsrust Gold Field was discovered. The area of paper *G*-3 is also now undergoing intensive prospecting and may also yet be proved a potential gold field.

TITLES OF GEOPHYSICAL PAPERS BY SOUTH AFRICANS

A. *General*

1. R. Krahmann, *Geophysical investigations in Southern Africa*. Beiträge zur angewandten Geophysik, IV, 88–116 (1934).
2. ———. *Geophysical investigations upon mineral deposits in Southern Africa* (Continuation til 1934). Beiträge zur angewandten Geophysik, V, 425–450 (1936).
3. O. Weiss, *The applications and limitations of geophysical prospecting methods in the Witwatersrand area*. J. Chem. Soc. S. Afr., XXXIV, 321–361 (1934).
4. ———. *The theory of rock bursts and the possibilities of geophysical methods in predicting rock bursts on the producing mines of the Witwatersrand*. J. Chem. Soc. S. Afr., XXXVIII, 273–329, 383, 467–471, 491–505, 562–570 (1938); XXXIX, 56–57 (1938); XXXIX, 188–197 (1939).

B. *Earthquakes*

1. L. J. Krige, and F. A. Venter, *The Zululand Earthquake of the 31st December, 1932*. Trans. geol. Soc. S. Afr., XXXVI, 101–112 (1934).
2. L. J. Krige, *The Swaziland and Fauresmith earthquakes of January, 1936*. Trans. geol. Soc. S. Afr., XXXIX, 429–440 (1937).

C. *Temperature Measurements in Boreholes*

1. L. J. Krige, and H. Pirow, *Temperature measurements in the Dubbeldevlei bore hole, Carnarvon district*. Trans. geol. Soc. S. Afr., XXVI, 50–64 (1923).
2. L. J. Krige, *Borehole temperatures in the Transvaal and Orange Free State*. Proceedings of the Royal Society of London, Series A, 173, 450–474 (1939).
3. O. Weiss, *Temperature measurements in a mine on the Witwatersrand with an electrical resistance thermometer*. J. Chem. Soc. S. Afr., XLV, 127-141 (1945).
4. ———. *Temperature measurements with an electrical resistance thermometer in a deep borehole on the East Rand*. J. Chem. Soc. S. Afr., XXIX, 149–166 (1938); XXXIX, 286–289 (1939); XL, 198–200 (1939).

D. *Absolute Magnetic Measurements*

1. L. C. Beattie, *Report of a magnetic survey of South Africa.* London, The Royal Society, 1909.
2. ———. *The secular variation of the magnetic elements in South Africa during the period 1900–1913.* Trans. R. Soc. S. Afr., IV, 181–203 (1914-1915).
3. ———. *Further magnetic observations in South Africa.* Trans. R. Soc. S. Afr., IV, 9–56 (1914).
4. ———. *True isogonics, isoclinals, and lines of horizontal intensity for the north-western parts of the Union of South Africa and for part of Great Namaqualand for the epoch July 1, 1908.* Trans. R. Soc. S. Afr., IV, 57–63 (1914).
5. ———. *Earth magnetism, with special reference to South Africa.* South African Association for the Advancement of Science, Report of the eighth annual meeting, October 31–November 5, 1910, pp. 14–28.

E. *Magnetic Prospecting* (See also G 1, G 5.)

1. O. Weiss, *Typical magnetic anomalies of lower Witwatersrand shales and younger dykes in the Witwatersrand.* J. Chem. Soc. S. Afr., XXXVI, 227–234 (1936).
2. O. Weiss, D. T. Simpson, and G. L. Paver, *Some magnetometric and gravimetric surveys in the Transvaal.* Department of Mines of the Union of South Africa, Geological Series Bulletin No. 7 (1936). 27 pages.
3. F. Bahnemann, *An instance of abnormal magnetic polarization in South Africa, together with a graphic method for determining effects of magnetic pole distribution.* Transactions of the American Institute of Mining and Metallurgical Engineers CXXXVIII, 161–172 (1940).
4. Hans Gelletich, *Über magnetitführende eruptive Gänge und Gangsysteme im mittleren Teil des Südlichen Transvaals.* Beiträge zur angewandten Geophysik, VI, 337–406 (1937).
5. R. Krahmann, *Magnetic investigations as an aid to economic geology.* Trans. geol. Soc. S. Afr., XXXIII, 65–87 (1930).
6. ———. *The geophysical magnetometric investigation on west Witwatersrand areas between Randfontein and Potchefstroom, Transvaal.* Trans. geol. Soc. S. Afr., XXXIX, 1–44 (1937).
7. ———. *Die magnetometrischen Untersuchungen am Witwatersrand.* Zeitschrift der deutschen geologischen Gesellschaft, LXXXIX, 79–87 (1937).
8. E. F. Fox, *The geophysical and geological investigation of the Far East Rand.* Trans. geol. Soc. S. Afr., XLII, 83–122 (1940).
9. B. D. Maree, *Notes on some magnetometric surveys with special reference to anomalies on Karoo dolerites.* Trans. geol. Soc. S. Afr., XLIV, 107–118 (1943).
10. G. L. Paver, *Magnetic anomalies in the Witwatersrand system. Explanation of Sheet No. 61 (Potchefstroom)*, Geological Survey, Government Printer, Pretoria, 1939, pp. 58–62.

F. *Electrical Resistivity Prospecting*

1. Oscar Weiss, *Preliminary observations on apparent electrical resistivity changes in rocks under stress and on E.M.F. caused by internal friction in rock fracturing.* Bulletin of the Institution of Mining & Metallurgy No. 462 (September 1943). 14 pages.
2. J. F. Enslin, *Basins of decomposition in igneous rocks: their importance as underground water reservoirs and their location by the electrical resistivity method.* Trans. Geol. Soc. S. Afr., XLVI, 1–12 (1943).

G. *Gravimeter and Torsion Balance Surveys* (See also E 2.)

1. Oscar Weiss, *Gravimetric and earth-magnetic measurements on the Great Dyke of Southern Rhodesia.* Trans. Geol. Soc. S. Afr., XLIII, 143–151 (1941).
2. R. Borchers, and G. V. White, *Preliminary contribution to the geology of the Odendaalsrust gold Field.* Trans. geol. Soc. S. Afr., XLVI, 127–153 (1943).
3. B. D. Maree, *The Vredefort structure as revealed by a gravimetric survey.* Trans. geol. Soc. S. Afr., XLVII, 183–196 (1944).
4. J. F. Enslin, *A comparison of the gravimetric and torsion balance methods of geophysical prospecting.* Trans. geol. Soc. S. Afr., XLVII, 283–299 (1944).
5. A. Frost, R. C. McIntyre, Edw. B. Papenfus, and O. Weiss, *The discovery and prospecting of a potential gold field near Odendaalsrust in the Orange Free State, Union of South Africa.* Trans. geol. Soc. S. Afr., XLIX, 1–24 (1946) (in press).

SOUTH AFRICAN SCIENTIFIC JOURNALS QUOTED

J. Chem. Soc. S. Afr.—Journal of the Chemical, Metallurgical, and Mining Society of South Africa.

Trans. geol. Soc. S. Afr.—Transactions of the Geological Society of South Africa. (The transactions are accompanied by a separate volume of the proceedings, which contain, *inter alia*, discussions on papers in the transactions.)

Trans. R. Soc. S. Afr.—Transactions of the Royal Society of South Africa.

The Transactions of the Geological Society of South Africa, which contain most of the papers, are sent to the following in Canada and the United States of America.

Academy of Natural Sciences, Philadelphia, Pa.
American Institute of Mining and Metallurgical Engineers, New York, N.Y.
American Journal of Science, New Haven, Conn.
California Academy of Sciences, San Francisco, Calif.
California Institute of Technology, Pasadena, Calif.
Congressional Library, Washington, D.C.
Field Museum of Natural History, Chicago, Ill.
Geological Society of America, New York, N.Y.
Geological Survey of Ohio, Columbus, Ohio
Journal of Geology, Chicago, Ill.
Maryland Geological Survey, Baltimore, Md.
Department of Mines, Ottawa, Ont.
Mississippi State Geological Survey, Jackson, Miss.
Missouri Bureau of Geology and Mines, Rolla, Mo.
National Academy of Sciences, Washington, D.C.
New York State Museum, Albany, N.Y.
United States Geological Survey, Washington, D.C.
Universities of California, Berkeley, and Los Angeles, Calif.

Gravity Measurements in Sjaelland, Møen, Falster, and Lolland by Means of the Askania-Gravimeter, by Einar Andersen, Geodaetisk Instituts Skrifter. 3. Raekke Bind X. København—1947, 69 pages, 17 figures.

La Rete Geofisica e Geodetica in Italia Nel Suo Stato Attuale e Nei Suoi Rapporti Con La Struttura Geologica Superficiale e Pronfonda, by Carlo Morelli, Instituto Geofisico—Trieste. Publ. n. 222. Trieste—1946, 77 pages, 3 plates, 11 figures.

The information in these publications constitutes an important contribution to the literature dealing with regional gravity and magnetic surveys. It can be used to good advantage in any correlation study between the geological and geophysical characteristics existing in Denmark and Italy.

The first publication describes the results of a gravity meter survey made in the Danish Islands east of Jutland during 1943 and 44. A total of 2474 different stations were occupied using an Askania gravimeter: of this number, 439, 17, and 2 stations were occupied twice, three times and four times respectively.

The method used for computing probable errors in the gravity observations as a function of the number of times a station is occupied is described in detail. The conclusions drawn are as follows: (a) the mean error for a station occupied once is $\pm$ 0.25 milligal, (b) the mean error for a station occupied twice is $\pm$0.18 milligal.

The gravity values are all referred to the pendulum reference station at Buddinge, which was occupied several times by the Baltic Geodetic Commission in 1930 and 1935. The Geodetic Institute has assigned a value of 981,558.1 milligals for this station. A catalog of the stations occupied is included in this publication. It contains values for latitude, longitude, elevation, observed gravity, Bouguer correction, the theoretical value based on Cassinis' formula

$$\gamma_0 = 978.0490\ (1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 \phi),$$

and the Bouguer anomaly. A Bouguer anomaly map on a scale of 1:320,000 having a contour interval of 1 milligal, is also included. It should be noted that a density value of 2.0 gm/cm^3 was assumed in calculating the Bouguer anomaly. This value is considerably lower than the one generally used, namely, 2.67, in computing this anomaly.

The second publication contains a catalog of 1471 magnetic stations occupied in Italy and Sicily during 1935. The latitude, longitude, elevation, declination, inclination, and horizontal field are among the information given for each station. In addition, a map showing the horizontal-field anomalies and one for declination are included. Both maps are on a scale of 1:2,500,000. Declination was measured with an accuracy of $\pm$1 minute, and the horizontal-field component to $\pm$30 gammas.

A catalog of 692 pendulum stations occupied in Italy and Sicily comprises the second half of this publication. Included in this figure are 83 observations made in the Tyrrhenian Sea and Adriatic Sea. The information contained in this catalog includes latitude, longitude, elevation, date of observation, value of gravity, the rock density given frequently to two decimal places, as well as several different gravity anomalies including free-air, Bouguer and isostatic. In addition, Bouguer and free-air anomalies are each plotted on a map having a scale of 1:2,500,000 and a contour interval of 20 milligals. A Hayford isostatic anomaly map, assuming a depth of compensation of 96 km., and also contoured at an interval of 20 milligals is included. The international gravity formula is used in all the computations. An accuracy of $\pm$1 milligal is claimed for the observations. In computing the marine gravity stations density values of 1.03, 2.67, and 5.52 were used for sea water, the earth's crust, and the mean density of the earth respectively.

The subject of changes in the value of gravity observed at the same station when the observations are separated by a substantial interval of time is also described in some

detail, and the data presented in 17 different tables. The results are in keeping with similar studies of this type made by other investigators. Although some of the values agree remarkably well, within several milligals over a period of 30–40 years, some extraordinarily large differences are reported; e.g., a difference of −105 milligals for a land station at Savonna between 1900 and 1939, and −164 between two observations made at sea in 1913 and 1935.

It is less difficult to account for the major discrepancy in the latter case, because it is conceivable that the observations were not made at exactly the same location in both instances. However, the difference of −105 for the land station is hard to explain entirely on the basis of systematic errors. Although this is an extreme value, differences varying between 25 and 50 milligals are not uncommon throughout these comparative tables.

R. A. GEYER

Photoelectric Cells. A. Sommer, Ph.D. Formerly, Cinema Television Co., Ltd. Chemical Publishing Co., Inc. New York (102 pages, $2.75). 1947.

The value of this Monograph can only be ascertained in relation to the audience which it reaches. The physicist, who is well acquainted with the laws governing photoelectric phenomena, will not find much new material. The electrical engineer, who is mostly concerned with photoelectric applications, will find the circuit discussion somewhat elementary in nature. This book is definitely not meant for the expert. It is intended for readers whose acquaintance with this general topic is only casual and who wish to acquire a solid foundation of the principles involved. The geophysicist may well come under this classification.

However, the book possesses an educational quality which will make it enjoyable reading for any audience. The author has the ability to present his theme in a logical form and to develop the early discoveries into the up-to-date knowledge in a manner which leaves the reader with the impression that the path taken since 1887 was one that could have been predicted.

The book deals with the emission-type photocell only, i.e., with the phenomenon of the liberation of photoelectrons in an electrostatic field due to light impinging on the cathode, and does not consider the barrier-layer types which give rise to an electromotive force of their own.

The first four chapters are devoted to the photocathode. The treatment stresses fundamental facts and, for the sake of clarity, idealizations and simplifications are found preferable to rigor. The photoelectric effect caused by a photon is stipulated by Einstein's Law which, after substitution of universal constants, relates the electron velocity to the wave length and the work function. Bohr's Model of the atom and the Periodic Table of elements are introduced.

The four fundamental conditions for photoelectric emission are then stipulated, viz. adequate absorption of light, low atomic binding force, low work function, specific resistance of semiconductor. In view of this physico-chemical background the main photocathodes are examined, especially the Ag-O-C and the Sb-C cathodes, the latter on the basis of the author's own research. Planck's Law of radiation for ideal black bodies is then studied and the photocathodes are re-examined from the standpoint of their action in the visible and invisible spectrum. The Bi-O-Ag-C cathode is

found to match closest the color response of the human eye. An interesting digression as to the outlook for future developments concludes Chapter IV.

The next two chapters are devoted to vacuum and gas-filled cells, and the fundamental difference between them is well-defined. Electron transit time, which governs the frequency response, and self-maintained discharge, which sets a limit to amplification, are discussed.

Chapter VII deals with the Multiplier Photocell, whose advantage lies in connection with amplification of very small light signals of short duration.

Chapter VIII treats Photocell Applications and is perhaps the weakest part of the book.

The bibliography refers to the most important work done on photoelectric cells during the period 1931 to 1945.

A. J. HERZENBERG

PUBLICATIONS RECEIVED

American Journal of Science, Vol. 245, No. 6 (June), No. 7 (July), No. 8 (August), and No. 9 (September), 1947.

No. 8. "Geosynclines: A Fundamental Concept in Geology, Part I," by M. F. Glaessner and C. Teichert, p. 465.

No. 9. "Geosynclines: A Fundamental Concept in Geology, Part II," by M. F Glaessner and C. Teichert, p. 571.

Annales de Géophysique, Tome 3, Fas. 1 (June, 1947).

Bulletin of Akademii Nauk, Nos. 8–9, 10, 11–12, 1946.

Economic Geology, Vol. 42, No. 4 (June-July, 1947).

Journal of Applied Physics, Vol. 18, No. 8 (August, 1947).

Journal of the Institute of Petroleum, Vol. 33, No. 282 (June, 1947) and No. 283 (July, 1947).

Nafta ("Petroleum"), Petroleum Institute of Poland, Krakow. Rok III, Nr 5 (May, 1947); Rok III, Nr 6 (June, 1947); and Rok III, Nr 7–8 (July–August, 1947).

Proceedings of the Cambridge Philosophical Society, Vol. 43, Part 3 (July, 1947).

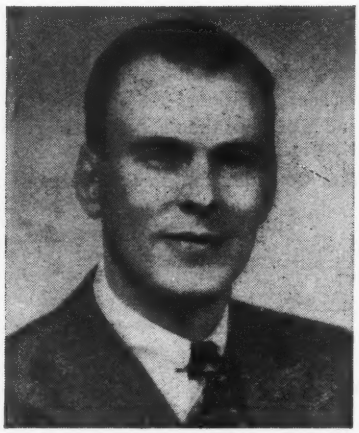
Review of Scientific Instruments, Vol. 18, No. 7 (July, 1947).

Revista Geomineraria, Anno II, N. 1 (January), N. 2 (April), N. 3–4 (July–October), 1941; Anno III, N. 1, N. 2, N. 3–4, 1942; Anno IV, N. 1, N. 2–3, N. 4, 1943; Anno V, N. 1–4, 1944; Anno VI e VII, 1945–1946.

Terrestrial Magnetism and Atmospheric Electricity, Vol. 52, No. 2 (June, 1947).

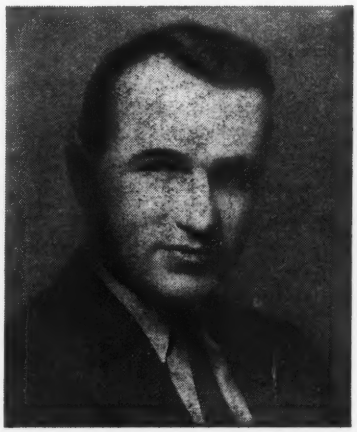
World Petroleum, Vol. 18, No. 7 (July, 1947), No. 8 (August, 1947).

CONTRIBUTORS



D. R. DOBYNS

D. R. DOBYNS received his B.S. degree in Electrical Engineering from the University of Kansas in January, 1927. Immediately upon graduation, he joined the geophysical laboratory of the Marland Oil Company where he assisted Drs. E. A. Eckhardt, R. D. Wyckoff, and Haseman in the development of the first gravity pendulum for petroleum expoloration, which he later took to the field, acting as party chief, computer and operator. In 1929, after Marland merged with Continental, Dobyns became the operator of a mechanical direct-recording seismograph and, subsequently, of Continental's first electrical seismograph. In April, 1933, he joined the Geophysical Research Corporation and in April, 1937, he transferred to the Magnolia Petroleum Company. He has been successively; observer, interpreter, field instrument supervisor, and is at present seismic supervisor of Magnolia's work in North Texas, Oklahoma, and Kansas.



L. DON LEET

L. DON LEET received the degree of B.S. in geology from Denison University in 1923 and Ph.D. in seismology from Harvard University in 1930. He did his first prospecting in 1928 with the G. R. C.'s water crew out of Houma, Louisiana, and has been in the field intermittently since: as Chief of a reflection party in Arkansas, 1935; and a refraction party seeking bauxite, 1940; part-owner of a crew in Alaska for alluvial gold, and in Canada for dam-sites, 1936–37; consultant for The Texas Company 1940 and 1947. He holds the position of Professor at Harvard University, where he has been in charge of the Seismograph Station since 1930. During the war, he served on the staff of Radio Research Laboratory and of Underwater Sound Laboratory at Harvard; recorded earth motion for the Manhattan District at the first Atomic Bomb test in New Mexico, 1945; went to Manila on a special mission for the Office of Field Service, OSRD. He has written a textbook, "Practical Seismology and

Seismic Prospecting," a popular book on "Causes of Catastrophe," and a manual, "Vibrations from Blasting," in addition to numerous articles in scientific periodicals.

ROBERT H. MANSFIELD studied at Deep Springs School, California, and Cornell University, Ithaca, N. Y., graduating from Cornell in February, 1932 with B.A. in Physics.

For the next three and one-half years, he was employed by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, first in their Washington laboratory, then in their geophysical observatory at Huancayo, Peru, and thereafter on a solo magnetic-survey assignment in South, East, and North Africa, followed by instrumental checks at observatories in England and Germany.

After a further year of study at the California Institute of Technology, he entered the employ of the United Geophysical Company, acting as computer, party chief, and seismologist for eight years in California and two years in Venezuela.

He is now seismologist for the Compania Consolidada de Petroleo at Caracas, Venezuela.

ROBERT H. MANSFIELD

THEODORE KOULOMZINE

THEODORE KOULOMZINE was born in St. Petersburg, Russia, in 1906. He left his native land in 1922, finished his secondary schooling in Czechoslovakia, received his Licencié ès Sciences at the Sorbonne University in Paris and his engineering degree in Strasbourg, France. Between 1929 and 1933, he was engaged in geophysical exploration in mining areas of Algeria, Morocco and France, and since early 1934, he established himself in Northwestern Quebec. In the last 13 years over 200 geophysical surveys have been performed in Canada by Koulomzine, Geoffroy, Brossard & Co. and its predecessor Techni-Counsel Ltd.

LEO BROSSARD

LEO BROSSARD is a partner in the firm of Koulomzine, Geoffroy, Brossard & Co., Consulting Geologists and Geophysicists, Val D'Or, Quebec. Born in 1912, he received degrees of B.A. from the College of Montreal in 1931, Bachelor of Applied Sciences from Montreal University in 1936 and Master of Science in Geology from McGill University in 1940. He was admitted a member of the Corporation of Quebec Land Surveyors in 1941. After several summers spent on various survey and prospecting parties and a short stage as Geologist at the Cournor mine, he entered consulting practice in Val D'Or and later joined the firm with which he is associated today. He is a member of the Society of Exploration Geophysicists, the Canadian Institute of Mining and Metallurgy, the Engineering Institute of Canada and the Corporation of Professional Engineers of Quebec.

KENNETH H. WATERS studied physics and mathematics at the Imperial College of Science and Technology, University of London, England, and in 1934 received the B.S. in Physics with first class honors. In 1936, he received the D.I.C. for postgraduate study in Applied Geophysics.

During the period 1936–1938, he worked on a Ph.D. thesis on a method of measuring susceptibilities of para- and dia-magnetic substances. He also held a demonstratorship and gave lectures in the Applied Geophysics and Geology departments.

In the summers of 1936 and 1937, he worked with Mr. A. Broughton Edge on electrical prospecting in Eire and in North-Wales.

In 1938, he came to the U.S. to work with the National Geophysical Company, Inc., and has held positions of computer, party chief, supervisor and research physicist. During the period of 1942 to 1945, he had leave of absence from the Company to engage in research on acoustics with the British Army.

KENNETH H. WATERS

Mr. Waters is a Fellow of the Physical Society of London and a member of the American Institute of Mining and Metallurgy, the American Geophysical Union and the Society of Exploration Geophysicists.

RAYMOND MAILLET was born in Nimes (Gard) on April 22, 1896. He studied at the Ecole Polytechnique in Paris from 1919 to 1920, and the National School of Mines in Paris from 1921 to 1922. Mr. Maillet belonged to the Interallied Control Commission of the Ruhr basin in 1923 and 1924. Since 1931, he has worked for Conrad and Marcel Schlumberger as General Manager of the Compagnie Generale de Geophysique, Paris. At the end of 1942, he resigned and became technical counsel of that firm.

RAYMOND MAILLET

E. D. ALCOCK

E. D. ALCOCK received an A.B. degree in Mathematics from U.C.L.A. in 1930 after which he worked for the Bell Telephone Laboratories for two years as a research engineer. He then returned to take his Ph.D. degree in physics at the California Institute of Technology, in 1935. After receiving his Ph.D., Dr. Alcock accepted employment in the geophysical industry, first with the Shell Petroleum Corporation, for whom he worked three years as a seismologist, and then with National Geophysical Company, with whom he is now employed.

PHIL P. GABY received the degree of B.S. in Chemistry and Mathematics from Southern Methodist University in 1931. After one year of seismograph field work for Geophysical Service, Inc., he attended the University of Texas, where he received the M.S. degree in 1933. Since that time, Mr. Gaby has been employed by Geophysical Service, Inc.; as computer until 1936, as party chief until 1941, and supervisor in California until May, 1946, at which time he resigned to take up a position as Consulting Geophysicist with the Standard Oil Company of California.

PHIL P. GABY

THE SOCIETY ROUND TABLE

STANDING COMMITTEES FOR THE YEAR 1947–48

1948 Annual Meeting

General Chairman

L. L. Nettleton, Gravity Meter Exploration Co., 1348 Mellie Esperson Bldg., Houston 2, Texas (Vice-President, S.E.G.)

Denver Arrangements Committee

C. A. Heiland, Chairman, Heiland Research Corp., 130 East Fifth Avenue, Denver 9, Colorado

Regional Program Committees

Pacific Coast

Curtis H. Johnson, Chairman, General Petroleum Corp. of California, 108 West Second Street, Los Angeles 12, Calif.
Raymond A. Peterson, United Geophysical Co., Pasadena, Calif.
John Sloat, Union Oil Co., Bakersfield, Calif.

Houston

H. G. Patrick, Chairman, Humble Oil & Refining Co., P. O. Box 2180, Houston 1, Texas
G. W. Carr, Carr Geophysical Co.
Ralph S. Jackson, Independent Exploration Co.
B. D. Lee, The Texas Company, Geophysical Lab.
John E. McGee, Gulf Research and Development Co.
Chester Sappington, General Geophysical Co.
F. A. van Melle, Shell Oil Co.

Dallas

A. E. McKay, Chairman, Atlantic Refining Co., Magnolia Bldg., Dallas 1, Texas
Kenneth E. Burg, Geophysical Service, Inc.
Paul E. Nash, Magnolia Petroleum Company
W. W. Newton, Geotechnical Corporation

Fort Worth

J. B. Lovejoy, Chairman, Gulf Oil Corp., P.O. Drawer 1290, Fort Worth, Texas
Fred J. Agnich, Geophysical Service, Inc.
Paul D. Balbin, Stanolind Oil and Gas Co.
Lynn K. Lee, Pure Oil Co.
John H. Wilson, Independent Exploration Co., Abilene, Texas

San Antonio

P. E. Navarte, Chairman, 307 Insurance Bldg., San Antonio 5, Texas
W. L. Crawford, Petty Geophysical Co.
Edward L. DeLoach, Atlantic Refining Co.
Thomas S. West, Blanco Oil Co.

Tulsa

R. W. Gemmer, Chairman, The Carter Oil Co., National Bank of Tulsa Bldg., Tulsa 2, Okla.
J. D. Eisler, Stanolind Oil & Gas Co.
A. J. Hintze, Phillips Petroleum Co., Bartlesville, Okla.
B. G. Swan, Continental Oil Co., Ponca City, Okla.

New Orleans

Joe B. Hudson, Chairman, Humble Oil & Refining Co., 2316 American Bank Bldg., New Orleans, La.
L. I. Brown, The California Co.
B. H. Treybig, Jr., The Texas Co.

Shreveport

George E. Wagoner, Chairman, The Carter Oil Co., Drawer 1739, Shreveport, Louisiana
H. M. Buchner, The Carter Oil Co.
L. F. Fischer, Sohio Petroleum Co.

Mississippi and Southeast

G. W. Gulmon, Chairman, Gulmon & Johns, Brynes Bldg., Natchez, Miss.
Ewin D. Gaby, Geophysical Service, Inc., Jackson, Miss.
Booth B. Strange, Western Geophysical Co., Natchez, Miss.
J. H. Todd, The California Company, Brookhaven, Miss.

Rocky Mountain

Walton H. Hohag, Jr., Chairman, General Petroleum Corp., P.O. Box 1652, Casper, Wyoming
Gerald Burton, Shell Oil Company
M. D. Tucker, Stanolind Oil & Gas Company
M. J. Walczak, Atlantic Refining Company

Eastern States

Sigmund I. Hammer, Chairman, Gulf Research & Development Co., P.O. Drawer 2038, Pittsburgh 30, Pa.
O. F. Ritzmann
Milton Dobrin

Canada

Theodore Koulomzine, Chairman, Koulomzine, Geoffroy, Broussard & Co., P.O. Box 870, Val D'Or, Quebec, Canada
Arthur A. Brant, Toronto University, Toronto
J. H. Hodgson, Toronto University, Toronto
Hans Lundberg, Consulting Engineer, Toronto
J. T. Randell, Geo-Technical Development Co., Ltd., Toronto

Geophysical Case Histories Volume

Henry C. Cortes, *Chairman*, Magnolia Petroleum Co., Dallas
L. F. Athy, Continental Oil Co., Ponca City

A. B. Bryan, Carter Oil Co., Tulsa
Kenneth Burg, Geophysical Service, Inc., Dallas
E. D. Alcock, National Geophysical Co., Dallas
Dave P. Carlton, Humble Oil & Refining Co., Houston
O. C. Clifford, Atlantic Refining Co., Dallas
Ira Cram, Pure Oil Co., Chicago
E. L. DeGolyer, DeGolyer & MacNaughton, Dallas
C. Hewitt Dix, United Geophysical Co., Pasadena
Milton Dobrin, Naval Ordnance Laboratory, Washington
J. Brian Eby, Consulting Geologist, Houston
Frank Goldstone, Shell Oil Co., Houston
H. J. Hintze, Phillips Petroleum Co., Bartlesville
W. E. Hollingsworth, Sun Oil Co., Beaumont
J. W. Hoover, The California Co., New Orleans
J. C. Karcher, Continental Bldg., Dallas
Joseph A. Sharpe, C. H. Frost Gravimetric Surveys, Tulsa
Henry Salvatori, Western Geophysical Co., Los Angeles
Louis A. Scholl, The Texas Co., Houston
L. O. Seaman, Sinclair Prairie Oil Co., Tulsa
D. C. Skeels, Standard Oil Co., of N. J., New York
L. H. Waterfall, Union Oil Co. of California, Los Angeles
B. B. Weatherby, Geophysical Research Corp., Tulsa
Paul Weaver, Gulf Oil Corp., Houston
G. H. Westby, Seismograph Service Corp., Tulsa

Constitution and By-Laws

Wm. M. Rust, Jr., *Chairman*, Humble Oil & Refining Co., Houston
J. J. Jakosky, Union Oil Co., Los Angeles
G. E. Wagoner, Carter Oil Co., Shreveport
L. L. Nettleton, Gravity Meter Exploration Co., Houston
Henry C. Cortes, Magnolia Petroleum Co., Dallas
Cecil H. Green, Geophysical Service, Inc., Dallas
J. F. Gallie, Cabot Corp. Pampa. Tex.

Special Reviews

R. A. Geyer, *Chairman*, Humble Oil & Refining Co., Houston
Florence Robertson, St. Louis University, St. Louis
C. Hewitt Dix, United Geophysical Co., Pasadena
Milton B. Dobrin, Columbia Univ., New York
Noyes D. Smith, Shell Explor. & Prod. Lab., Houston
Henry R. Joesting, U. S. Geological Survey, Washington

Student Membership

James C.Menefee, *Chairman*, Magnolia Petroleum Co., Dallas
Ralph S. Jackson, Independent Exploration Co., Houston
Darrell S. Hughes, University of Texas, Austin
S. A. Lynch, Texas A. and M. College, Bryan
C. Hewitt Dix, United Geophysical Co., Pasadena

John H. Hodgson, University of Toronto, Toronto
V. L. Jones, University of Tulsa, Tulsa
Ralph C. Holmer, Colorado School of Mines, Golden

Best Paper Award

Roland F. Beers, *Chairman*, Geotechnical Corp., Dallas
W. T. Born, Geophysical Research Corp., Tulsa
Frank Goldstone, Shell Oil Co., Inc., Houston
M. King Hubbert, Shell Oil Co., Inc., Houston
Frederick E. Romberg, La Coste & Romberg, Austin
Paul Weaver, Gulf Oil Corp., Houston

Geophysical Education

James B. Macelwane, S. J., *Chairman*, St. Louis University, St. Louis, Mo.
Perry Byerly, University of California, Berkeley
Maurice Ewing, Columbia University, New York
Beno Gutenberg, California Institute of Technology, Pasadena
C. A. Heiland, Heiland Research Corp., Denver
M. King Hubbert, Shell Oil Co., Inc. Houston
D. C. Skeels, Standard Oil Co. of New Jersey, New York

Public Relations and Publicity

G. E. Wagoner, *Chairman*, Carter Oil Co., Shreveport
M. R. Budd, Hercules Powder Co., Wilmington, Del.
C. C. Campbell, Society of Exploration Geophysicists, Tulsa

Annual Survey of Geophysical Activity

E. A. Eckhardt, *Chairman*, Gulf Research & Development Co., Pittsburgh

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the President within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Walter H. Amis, Jr.
A. E. McKay, John A. Gillin, W. W. Newton
Santi Lal Banerjee
Maurice Ewing (Art. III-D-1 of the Constitution)
Robert Forest Bauer
J. J. Jakosky, E. J. Handley, Opie Dimmick
Edward Everett Brown
Glenn E. Bader, H. G. Patrick, M. M. Slotnick
Russell Bernard Cornell
J. C. Menefee, W. M. Tottenham, R. M. Nugent

William Hunter Gibson
L. A. Scholl, Jr., Roy L. Lay, Homer C. Moore
Edward Walter Hans
C. D. Whitsitt, W. Harlan Taylor, C. H. McAlister
James Clayton Harper, Jr.
W. T. Born, J. E. Owen, W. B. Kendall
Clifford Graves Haynes
A. F. Dugan, H. E. Granberry, W. B. Raper
Edwin F. Helser
H. R. Moorman, P. P. Conrad, Albert J. Z. Caan
Eldon Woodrow Langford
J. E. Stones, Frank Ittner, Cecil E. Reel
Curtis Ewing Macon
John A. Gillin, B. J. Sorrells, E. D. Alcock
Joe Jackson McCullough
Opie Dimmick, E. J. Handley, J. J. Jakosky
Fred Lee McMillan, Jr.
R. B. Rice, A. E. Tilley, R. G. Piety
Adolf Metzger
(Art. III-D-1 of the Constitution)
James Campbell Montgomery
A. L. Selig, Austin S. Rogers, Bill Henderson
John Charles Palmer
Albert Taylor, A. I. Innes, L. Y. Faust
Glen Peterson
A. E. Tilley, R. B. Rice, R. G. Piety
Maxwell Addison Phillips
James Affleck, Paul O. Fink, T. J. O'Donnell
Luther Clinton Powell
E. J. Stulken, O. A. Strange, N. J. Smith
Bernhard E. Richert
F. L. Johnson, W. G. Smiley, Jr., L. G. Ellis
Lewis Daniel Strutzel
Robert H. Ray, J. C. Pollard, W. Raymond Griffin
Ludwig Marinus Heinrich Vreugde
F. Goldstone, W. Hafner, L. K. Mower
Edward Francis Zagst
F. F. Reynolds, R. R. Rosenkrans, H. H. Happel

ASSOCIATE

Albert E. Benson
Arland I. Innes, Andrew Gilmour, Paul H. Jeffers
Mona Dennis Guiler
R. A. Geyer, W. M. Rust, Jr., M. M. Slotnick
Noel Robertson Park
Chester Sappington, Julian K. Pawley, Neal J. Smith
George Jordan Petsoff, Jr.
A. J. Barthelmes, G. H. Westby, Robert Baum

Harmen Jan van der Platts
F. Goldstone, J. E. Walker, F. A. Van Melle
Robert M. Tesar
W. L. Irby, Geo. G. Walton, W. W. Clark
Allan Pavey Watson
A. J. Barthelmes, G. H. Westby, Robert Baum

TRANSFER TO ACTIVE

Tun Yin Chang H. E. Stommel

RE-STATEMENT

Alfred Schleusener

RESIGNATION

H. W. Hole Paul W. Klipsch

REPORT OF THE SECRETARY-TREASURER ON THE CONSTITUTIONAL BALLOT

It is my pleasure to report the results of the vote on the new constitution for the Society which was recently submitted to the Membership.

Since the ballot provided for a blanket "Yes" or "No" vote on the entire Constitution and also for individual approval or disapproval of each of the main revisions, the tabulation was handled in the following manner: first the vote was divided into those who voted "Yes," those who voted "No," those whose vote was not counted due to some difficulty or mistake on the ballot, and those who did not vote on the Questions submitted; and second, the vote was divided into the Main Question and Revisions One, Two, Three, Four, Five, Six, Seven and Eight, using the first classification to check the vote.

The summaries, therefore, show that 616 people voted. By category the vote is classified:

MAIN QUESTION: Do you approve the adoption of the revised CONSTITUTION AND BY-LAWS, approved for submission to the Members by the Business Committee and the Members in attendance at the Los Angeles Annual Meeting?

Voting "Yes"	545
Voting "No"	29
Ballots Scratched	17
Those who did not vote	25
	616

REVISION ONE. A new class of member, the Fellow, is established by the new Article III, Sections 2 and 3 with details in Bylaw II.

Voting "For"	575
Voting "Against"	22
Ballots Scratched	17
Those who did not vote	2
	616

REVISION TWO. The requirements for election to Active Membership are made definite and more restrictive. This does not affect present Active Members, only future ones. The proposed Article III, Section 5 reads: *"To be eligible to election to Active Membership an applicant must have been actively engaged in practising or teaching geophysics or a related field for not less than eight years (Up to four years as a student in a recognized college or university may be counted toward this total) of which at least three years must have involved work of a responsible nature calling for independent judgment and the application of geophysical or geological principles."*

Voting "For"	566
Voting "Against"	13
Ballots Scratched	17
Those who did not vote	0
	616

REVISION THREE. The requirements for election to Associate Membership have been made definite and less restrictive. The proposed Article III, Section 6, reads: *"To be eligible to election to Associate Membership, an applicant must be actively interested in geophysics."*

Voting "For"	583
Voting "Against"	13
Ballots Scratched	17
Those who did not vote	3
	616

REVISION FOUR. A definite *CODE OF ETHICS* is incorporated in Article IV of the proposed revision.

Voting "For"	586
Voting "Against"	10
Ballots Scratched	17
Those who did not vote	3
	616

REVISION FIVE. In the proposed Article VIII, a COUNCIL is substituted for the present Business Committee. The Council will be a large group including representatives of the members in various Sections and Districts and will be the governing body of the Society. The Executive Committee will, as at present, conduct most of the routine business of the Society, but the Council can, at any time, meet and overrule and instruct the Executive Committee.

Voting "For"	591
Voting "Against"	5
Ballots Scratched	17
Those who did not vote	3
	616

REVISION SIX. In the present By-law III-A, Section 1, general provision is made for "Regular Sections" of the Society. In the proposed Article XI, together with proposed By-laws VIII and IX, these provisions are made more definite, the Local Section is given representation on the Council and the Society agrees to give the Local Section financial assistance.

Voting "For"	588
Voting "Against"	4
Ballots Scratched	17
Those who did not vote	7
	616

REVISION SEVEN. In the present By-law IV, the Executive Committee is given permission to provide for the election of District Representatives. This has not proved to be practical; no District Representatives have ever been elected. In the proposed Articles XI and XII, District Representatives are made mandatory and are members of the governing Council. It is provided that where Local Sections are organized, they shall elect Representatives. The remainder of the United States is to be divided into seven districts and the President of the Society shall appoint Representatives from these Districts.

Voting "For"	589
Voting "Against"	2
Ballots Scratched	17
Those who did not vote	4
	616

REVISION EIGHT. As a guarantee that the Members of the Society shall have full control of the Society, the proposed Article XVI provides a method for the Members to force the modification of any action of the Officers, Council or Committees, should an occasion ever arise where this is desirable.

Voting "For"	593
Voting "Against"	2
Ballots Scratched	17
Those who did not vote	4
	616

Therefore, it is apparent that the new constitution has been carried by a big majority. In an effort to analyze the criticisms of the constitution, a summary has been made of all of the comments appearing on the ballots. This summary has been submitted to the Executive Committee for consideration. Members submitting objections are referred to Article XVIII of the Constitution which outlines the procedure for amendments.

The new Constitution and By-Laws became effective August 12, 1947, the closing date of the voting period.

Respectfully submitted,
T. A. MANHART, *Secretary-Treasurer*

1948 ANNUAL MEETING

The 1948 Annual Meeting of the Society of Exploration Geophysicists will be held in Denver, Colorado, in conjunction with the Annual Meetings of the A.A.P.G. and S.E.P.M. Headquarters will be the Shirley-Savoy Hotel. The dates are April 26–29.

Present plans are to hold a half day sympoium on applications of geophysics in the mining industry and papers on such applications or on mining problems possibly susceptible to geophysical attack are particularly desirable. The remainder of the geophysical sessions (two half days and possibly an evening) will be devoted to the more usual type of technical and exploration papers. It is hoped that the great interest in geophysical case histories, which has developed during the past two years, may be continued by further papers of this type.

Regional program committees for this meeting have been named as announced in the July 1947 (Vol. XII, No. 3) issue of GEOPHYSICS. Those who have possible program material or know of others who may be able to present suitable papers for the meeting can help greatly by contacting some member of these committees as soon as possible.

Prospective authors are referred to the paper on "Preparation of Manuscripts for Publication in GEOPHYSICS" (Vol. X, No. 3, July 1945) particularly with respect to the preparation of diagrams or maps for slides or for page-size reproductions.

L. L. NETTLETON
General Chairman
Program Committee for 1948 Meeting

ANNOUNCEMENT OF PACIFIC COAST MEETING

The joint fall regional meeting of the S.E.G., the A.A.P.G. and the S.E.P.M. will be held November 6 and 7 at the Huntington Hotel in Pasadena, California.

The Society of Exploration Geophysicists has scheduled a full day technical program November 6; the A.A.P.G. two days, November 6 and 7; and the S.E.P.M. a combined technical session and dinner on November 6. There will be a minimum of conflict between the S. E. G. and A.A.P.G. programs since the A.A.P.G. is planning a symposium on "Production from Fractures" for November 6 and reserving the 7th for papers of interest to both geologists and geophysicists.

In planning the S. E. G. program, the committee remembered the popularity of the symposium on "Multiple Reflections" led by Ted Ellsworth last year; and, after canvassing a fairly large representative portion of the membership for recommendations, has scheduled for the morning session a symposium on "Correlations in California." John Sloat has consented to prepare the lead paper, and several other members have agreed to prepare written and illustrated discussions. Four papers of general interest are definitely scheduled for the afternoon session.

A joint luncheon is planned for November 6, a joint dinner dance the evening of November 7. By coincidence the Stanford and U.S.C. Elevens will battle it out on the gridiron Saturday November 8 at the Los Angeles Coliseum.

The members of the S. E. G. Program Committee are: Curtis H. Johnson, Chairman, John Sloat, and Raymond A. Peterson.

NOMINEES FOR 1948-49 EXECUTIVE COMMITTEE

The following brief biographical sketches are presented in an attempt to acquaint members of the Society with nominees appearing on the official ballot for the coming year.

FOR PRESIDENT

L. L. NETTLETON

JOHN H. WILSON

L. L. NETTLETON received his B.S. degree from the University of Idaho in 1918 and his Ph.D. degree (in Physics), from the University of Wisconsin in 1923. From 1923 to 1928 he was engaged in electrical research and development in the research department of the Union Switch & Signal Company at Swissvale (Pittsburgh), Pa. From 1928 to 1946 he was in the research laboratory of the Gulf Research & Development Company where he had charge of the interpretation and mapping of all gravity work (torsion balance, pendulum and gravimeter) carried out by the Gulf Oil Corporation. In July 1946, he joined Gravity Meter Exploration Company, Houston, Texas, as a partner in the firm.

For some ten years, Dr. Nettleton was advisory Professor of Physics at the University of Pittsburgh and gave a course of lectures on geophysical prospecting. These lectures were the background of his book "Geophysical Prospecting for Oil," published in 1940. Also he has been much intreested in dynamic geology and the relation of geophysics, especially gravity, to geology. This work is best known through his fluid mechanical concept and fluid models of the formation of salt domes. His journal publications include papers on gravity and magnetic prospecting and calculations, relation of gravity to geologic structure, sources of magnetic and density contrasts, mechanics of salt domes and scale models.

Dr. Nettleton is a member of the American Physical Society, American Association of Petroleum Geologists, American Geophysical Union, American Association for the Advancement of Science, Geological Society of America, Houston Geological Society and of the Society of Exploration Geophysicists. He served as editor of GEOPHYSICS for

two years and is now Vice-President of the Society; also he is continuing as general editor of the special volume of Geophysical Case Histories.

JOHN H. WILSON received the degree of E.M. in 1923 from the Colorado School of Mines. Upon graduation he joined the geological staff of the Midwest Refining Company at Denver, Colorado, doing field work in Colorado, Wyoming, Utah, Arizona, Kansas and Texas in 1923 and 1924. He was in charge of subsurface laboratory and core drilling for that company from 1924 to 1926. From 1926 to 1927 he was in charge of core drilling and geophysical work for the Huasteca Petroleum Company at Tampico, Mexico. He was assistant professor of geophyics at the Colorado School of Mines in 1928 and 1929; consulting geologist and geophysicist from 1929 to 1934; President of the Colorado Geophysical Corporation from 1934 to 1937; Vice-President, Independent Exploration Company from 1937 to date.

Mr. Wilson is a member of the American Association of Petroleum Geologists, Fort Worth Geological Society (President, 1946), American Geophysical Union, Society of Exploration Geophysicists (Secretary, 1936), and an associate member of the American Institute of Mining and Metallurgical Engineers. He is a member of Alpha Tau Omega social fraternity and Sigma Gamma Epsilon honorary fraternity.

FOR VICE-PRESIDENT

ANDREW GILMOUR

WALTER J. OSTERHOUDT

ANDREW GILMOUR received his B.Sc. degree from Queen's University, Belfast, Ireland in 1918 and his M.Sc. from the National University of Ireland in 1919. In 1920 and 1921 he was engageed in research work for the British Admiralty at the Admiralty Laboratories, Teddington, Middlesex, England.

In 1922 he came to Amerada Petroleum Corporation to do Torsion Balance work and has been with Amerada and its affiliated companies continuously since that time. From 1928 to 1930 he supervised geophysical work for Amerada in California. Since

1930 he has been supervising geophysical work, mainly seismograph work, in the Mid-Continent. He is now Chief Geophysical Supervisor for Amerada Petroleum Corporation.

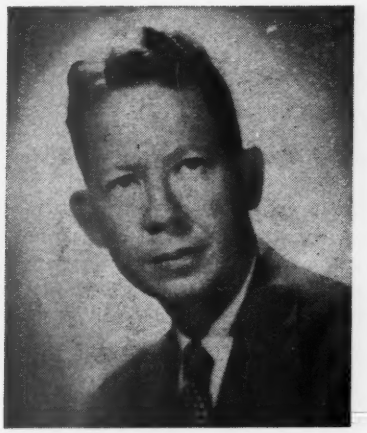
He is a member of the Society of Exploration Geophysicists (Secretary-Treasurer 1940–1941), American Association of Petroleum Geologists, American Geophysical Union, American Association for the Advancement of Science, The Tulsa Geological Society, and the Geophysical Society of Tulsa.

WALTER J. OSTERHOUDT received the B.A. degree in Physics, with Geology as a minor, from the University of Wisconsin in 1930. He was employed as an assistant laboratory technician by Gulf Research & Development Company in June 1930. Assigned to seismograph research and development, he entered field work with Gulf's first seismograph party in January, 1931. After field trials in Kentucky and Ohio, he helped to start Gulf Research & Development Company's seismograph exploration in Louisiana, Texas, Oklahoma, California, Mexico and Venezuela. In October, 1935 he was assigned to the Houston Division of the Gulf Oil Companies as a supervisor of Gulf Research & Development Company's seismograph operations. In 1936 and 1937 he became interested in the erratic weathered zone conditions in the Mississippi delta area in Louisiana, and did considerable seismograph work which led to the mapping of portions of the buried Mississippi River Canyon. The preliminary report of his study has been presented to the Society of Exploration Geophysicists and to the Geological Society of America.

Mr. Osterhoudt is a member of the Society of Exploration Geophysicists, American Association of Petroleum Geologists, The Texas Society of Professional Engineers, The Texas Academy of Science and the Houston Geological Society. He has served the S. E. G. as a member of the Houston Program Committee for the past three years, being Chairman of the Program Committee and Chairman of the Houston Regional Meeting in 1947.

FOR SECRETARY-TREASURER

E. V. MCCOLLUM



A. E. MCKAY

E. V. McCollum received his A.B. degree in 1925 and his M.S. degree in 1926, both from the University of Oklahoma. He was employed by the Marland Oil Company from June, 1926 to July, 1929, where he served as party chief of field parties engaged in pendulum and torsion balance measurements. In 1929 he was employed by the Continental Oil Company as party chief until 1933 when he became Control Geophysicist. In May, 1939 he was employed by the Mott-Smith Corporation as chief geophysicist. Since September, 1943 he has been associated with E. V. McCollum & Co. as a partner.

Mr. McCollum is a member of the American Physical Society, the American Geophysical Union, the Seismological Society of America, the Tulsa Geological Society, the Geophysical Society of Tulsa, and the Society of Exploration Geophysicists.

A. E. (Sandy) McKay, Assistant Chief Geophysicist for The Atlantic Refining Company, Dallas, Texas, graduated from the Univeristy of Oklahoma in 1928 with a B.S. degree in Geology. He then joined The Indian Territory Illuminating Oil Company, serving as magnetometer operator, core drill geologist, surface and subsurface geologist. He entered seismic work early in 1933, holding most all positions on field parties for Seismograph Service Corporation, Phillips Petroleum Corporation, and The American Seismograph Company, returning to The Indian Territory Illuminating Oil Company in late 1934 when that company established a geophysical section. He served as computer, party chief, and supervisor with that company until 1937 when he joined The Atlantic Refining Company as District Coordinator of geological and geophysical work in the Louisiana-Arkansas district, Cuba and West Texas.

Early in 1942 Mr. McKay was called to active duty in the Army Air Forces, serving until late 1944 when, as a Major, he was returned to inactive status. At this time he rejoined The Atlantic Refining Company in Dallas, Texas, in the position he now holds.

Mr. McKay is a member of the American Association of Petroleum Geologists, Dallas Geological Society, Society of Exploration Geophysicists, and served as Chairman of the Program Committee of S. E. G., Dallas area, in 1946 and 1947.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS
CONSTITUTION AND BY-LAWS

(As amended to April 1947)

Article I. Name

Section 1. This Society shall be called the "Society of Exploration Geophysicists."

Article II. Object

Section 1. The objects of this Society shall be to promote the science of geophysics especially as it relates to exploration and research, to foster the common scientific interests of geophysicists, and to maintain a high professional standing among its members.

Article III. Membership

Section 1. The membership of this Society shall consist of persons elected and qualified in accordance with the Constitution and bylaws of this Society at the time of such election.

Section 2. The membership of this Society shall consist of Honorary Members, Fellows, Active Members, Associate Members, and Student Members.

Section 3. To be eligible to election to Honorary Membership a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have made a distinguished contribution to geophysics or a related field which warrants exceptional recognition.

Section 4. To be eligible to election as a Fellow, a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have done outstanding work in geophysics or a related field and shall have been an Active Member in good standing for ten or more years or have been an elected officer of the Society.

Section 5. To be eligible to election to Active Membership an applicant must have been actively engaged in practising or teaching geophysics or a related field for not less than eight years (up to four years as a student in a recognized college or university may be counted toward this total) of which at least three years must have involved work of a responsible nature calling for independent judgment and the application of geophysical or geological principles.

Section 6. To be eligible to election to Associate Membership, an applicant must be actively interested in geophysics.

Section 7. To be eligible to election to Student Membership an applicant must be a graduate or undergraduate student in good standing in residence at a recognized university or college.

Section 8. An Honorary Member, Fellow or Active Member shall enjoy all privileges of the Society. He shall be eligible to hold any office, to vote on all matters submitted to the membership, to petition the Council or Executive Committee on any matter, to sponsor applicants for membership and to publish his affiliation with the Society.

Section 9. An Associate Member or Student Member shall be entitled to attend the meetings of the Society, to receive its Journal and to purchase its publications, on the same terms as an Active Member. He shall have none of the other privileges of membership and may not publish his affiliation with the Society. Student Membership shall terminate one year after the Student Member ceases to be enrolled at a recognized university or college.

Article IV. Code of Ethics

Section 1. All members of the Society shall subscribe to the following code of ethics.

Code of Ethics

That the dignity of his chosen profession may be maintained, it is the duty of every member of the Society

1. To carry on his professional work in a spirit of fairness to employees and contractors, fidelity to clients and employers, and devotion to high ideals of personal honor.

2. To refrain from associating himself with, or allowing the use of his name by, any enterprise of questionable character.

3. To treat as confidential his knowledge of the business affairs, geophysical or geological information, or technical processes of clients or employers when their interests require secrecy.

4. To inform a client or employer of any business connections, interests, or affiliations which might influence his judgment or impair the disinterested quality of his services.

5. To accept financial or other compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.

6. To advertise only in a dignified manner, to refrain from using any improper or questionable methods of soliciting professional work, and to decline to pay or to accept compensation for work secured by such improper or questionable methods.

7. To refrain from using unfair means to win professional advancement and to avoid unfairly injuring another geophysicist's chances to secure and hold employment.

8. To cooperate in building up the geophysical profession by the interchange of general information and experience with his fellow geophysicists and with students and also by contributions to the work of technical societies, schools of applied science, and the technical press.

9. To interest himself in the public welfare and to be ready to apply his special knowledge, skill, and training in the public behalf for the use and benefit of mankind.

Section 2. It shall be the duty of any member of the Society having cognizance of a violation of this Code of Ethics by any other member to report confidentially in writing the details of such violation to the President of the Society, who shall forward a copy of the report to all members of the Executive Committee for investigation. The President shall destroy the original report and shall under no circumstances divulge the name of the member making the report. The Executive Committee shall hold all information relating to the charge and their investigation in complete confidence until such time as they may agree unanimously upon the disciplinary action to be taken.

Article V.

Election, Resignation and Expulsion of Members

Section 1. The method of election to the various grades of membership shall be as set forth in the Bylaws.

Section 2. Any member in good standing may resign from the Society at any time as set forth in the Bylaws.

Section 3. Any member may for the good of the Society be suspended or expelled from the Society at any time as set forth in the Bylaws.

Article VI. Officers

Section 1. The officers of the Society shall be a President, a Vice-President, a Secretary-Treasurer, and an Editor. Officers shall be elected in the manner prescribed in the Bylaws for a term of one year with the exception of the Editor, whose term shall e two years.

Section 2. Election of officers shall be by secret mail ballot. On the ballot shall be printed the nominees for each office arranged in alphabetical order.

Section 3. The Standing Committee on Nominations shall nominate, in the manner prescribed in the Bylaws, two candidates for each office to be filled. Further nominations may be made by petition as set forth in the Bylaws.

Section 4. The officers shall assume the duties of their respective offices immediately after the close of the Annual Meeting following their election.

Section 5. No officer shall be eligible for election to the same office for two consecutive terms.

Section 6. In case of a vacancy in any office, other than the President's, the Executive Committee shall select a successor to serve until the close of the annual meeting following this appointment.

Article VII. Duties of Officers

Section 1. The President shall be the presiding officer at all the meetings of the Society, shall take cognizance of the acts of the Society and of its officers, shall appoint such Standing Committees and special committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee. He shall prepare an address to be given before the members of the Society at the Annual Meeting.

Section 2. The Vice-President shall assume the office of President in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or disability of the latter. He shall also be responsible for all National Meetings of the Society.

Section 3. The Secretary-Treasurer shall assume the duties of the President in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as Secretary-Treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the Journal of the Society. Under the direction of the Council, he shall arrange for the receipt and disbursal of all Society funds. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded, all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the Council and the expense shall be borne by the Society.

Section 4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

Article VIII. Council

Section 1. The Council of the Society shall consist of the officers, the Past President, the Past Prior President, the District Representatives and the Chairmen of all Standing Committees.

SECTION 2. The Council shall be the governing body o' the Society and subject to the provisions of the Constitution and Bylaws shall have full control and management of the affairs and funds of the Society.

SECTION 3. A joint meeting of the outgoing and incoming Councils shall be held at the call and under the Chairmanship of the newly elected President during or within seven days after the Annual Meeting of the Society. At this joint meeting the Councils shall hear reports from all Officers and Committees and review the activities of the Society for the past year. With the advice of the outgoing Council, the incoming Council shall conduct any necessary business and issue instructions or recommendations to any officer or committee, subject to the provisions of the Constitution and Bylaws.

SECTION 4. At the call of the President or a majority of the Council members, and after written notice to all Council members, the Council may meet at any time.

SECTION 5. A quorum at any meeting of the Council shall consist of six Council members.

SECTION 6. Unless otherwise provided by the Constitution, all actions by the Council shall require a majority vote of the members present.

ARTICLE IX. EXECUTIVE COMMITTEE

SECTION 1. The Executive Committee shall consist of the President, the Vice-President, the Secretary-Treasurer, the Editor, and the Past President.

SECTION 2. When the Council is not in session the Executive Committee shall have full authority, subject only to prior instructions by the Council, to exercise all powers of the Council.

SECTION. 3. All actions of the Executive Committee shall require a majority vote of all members of the Committee.

SECTION 4. The Executive Committee may vote on any matter either by mail or in person.

ARTICLE X. MEETINGS

SECTION 1. The Society shall hold at least one meeting of the members each year, this meeting to be known as the Annual Meeting. One session of this meeting shall be a Business Meeting, at which reports of the Officers and Committees shall be read and the results of the mail ballot for officers announced.

SECTION 2. The Annual Meeting shall be held at a time and place designated by the Executive Committee.

SECTION 3. Additional meetings of the Society may be called by the Executive Committee.

ARTICLE XI. LOCAL SECTIONS

SECTION 1. Local sections, consisting of members of the Society and other persons engaged in geophysics or a related field residing within an appropriate distance of a central point, may be organized as provided in the Bylaws.

SECTION 2. Each local section shall assist in carrying out the objectives of the Society within the territory assigned to the section by the Council.

SECTION 3. Each local section shall have one district representative if among its members there are less than seventy-five Honorary Members, Fellows and Active Members of the Society in good standing, two district representatives if more than seventy-five and less than one hundred fifty, or three district representatives if more than one hundred fifty.

SECTION 4. The district representatives shall be elected from among the Honorary Members, Fellows and Active Members of the Society in good standing for terms stated and in the manner prescribed in the Bylaws and shall not be eligible for two consecutive terms.

ARTICLE XII. DISTRICTS

SECTION 1. The Council shall divide the area of the continental United States, not assigned to local sections, into not more than seven districts.

SECTION 2. No district shall contain less than fifty nor more than one hundred fifty active members of the Society, except that the area, not assigned to local sections, within a state shall all be within a single district.

SECTION 3. Each district shall have one district representative, who shall be appointed by the President for a term of one year expiring at the close of the Annual Meeting.

ARTICLE XIII. AFFILIATED SOCIETIES

SECTION 1. The Council may arrange for affiliation of the Society with any duly organized groups or societies.

SECTION 2. The terms of affiliation must provide that the Society shall have the right to dissolve such affiliation at any time, subject only to the payment of any sums it may legally owe the affiliated group or society.

ARTICLE XIV. COMMITTEES

SECTION 1. In addition to the Executive Committee, there shall be appointed Standing Committees to further the purposes of the Society.

SECTION 2. The duties of the Standing Committees and the method of their appointment shall be in accordance with the Bylaws.

SECTION 3. The President may at any time appoint Special Committees for such purposes as he may deem fit.

SECTION 4. The terms of all Special Committees shall expire at the close of the Annual Meeting following their appointment.

ARTICLE XV. BUSINESS MANAGER

SECTION 1. The Council may employ a Business Manager for the Society and pay him such salary and other compensations from the Society's funds as they deem advisable.

SECTION 2. The Business Manager shall provide a bond appropriate in amount, the cost to be borne by the Society.

SECTION 3. The Business Manager shall, under the supervision of the Secretary-Treasurer, perform such duties as the Council may assign him.

SECTION 4. The Council may discharge the Business Manager at any time.

ARTICLE XVI. REVIEW BY MEMBERS

SECTION 1. All acts of the Officers, Council, and Committees of the Society shall be subject to review by the members.

SECTION 2. Proposals to change any decision, policy or procedure of any Officer, the Council, or any Committee shall be submitted in writing to the President and signed by at least twenty-five Honorary and Active Members or Fellows in good standing.

SECTION 3. Upon receipt of such a petition with a sufficient number of valid signatures, the President shall advise the Council and the Officer or Committee involved.

SECTION 4. Should the Officer or Committee involved be unwilling to comply with the petition, it, together with a discussion by the proposer and the Officer or Committee involved, shall be published in the next issue of the Society's Journal.

SECTION 5. Within thirty days after publication in the Journal, the petition shall be submitted to the membership by mail ballot by the President. A majority of the ballots returned within thirty days after being mailed by the President shall be decisive. Should the vote favor the petition, it shall be complied with, within the limitations imposed by the Constitution and Bylaws, as promptly as practicable.

ARTICLE XVII. BYLAWS

SECTION 1. The Council shall make such Bylaws not in conflict with the Constitution, as it may deem necessary for the proper government of the Society. The Council may amend the Bylaws at the annual joint meeting by an affirmative vote of two-thirds of the members of the incoming Council present. All proposed amendments must, however, be published in the Society's Journal before being submitted to the Council.

ARTICLE XVIII. AMENDMENTS TO THE CONSTITUTION

SECTION 1. Amendments to this Constitution may be proposed by any ten members of the Society, by any Officer of the Society, or by a Constitutional Committee appointed by the President.

SECTION 2. Any proposed amendment shall be submitted to the President in time for publication in the Society's Journal prior to the Annual Meeting.

SECTION 3. At the annual joint meeting of the Council, all proposed amendments received since the previous annual meeting, shall be considered. Those receiving approval from a majority of the members of the incoming Council present shall be submitted by mail ballot, arranged by the Secretary-Treasurer, to the entire membership of the Society within sixty days. If a majority of the ballots returned within sixty days of their mailing favor the proposed amendment, it shall become effective at the expiration of this sixty days. All amendments shall be reported in the Society's Journal.

BYLAWS

ARTICLE I. PUBLICATIONS

SECTION 1. The Society shall publish a Journal entitled GEOPHYSICS.

SECTION 2. The Journal shall be published at intervals designated by the Executive Committee.

SECTION 3. All reports to the Society by its officers and committees shall be published in the Journal. All members of the Society shall be presumed to have due notice of all Society matters published in the Journal. Each issue shall contain a membership list of all Standing and Special Committees.

SECTION 4. Original papers, reviews, abstracts, notes or letters containing information deemed by the Editor to be of interest to the members of the Society shall be published in the Journal. The Editor shall be the sole judge of whether such material is to be published.

SECTION 5. The subscription rate of the Journal shall be $6.00 ($6.50 foreign) per year to non-members and $3.00 per year to members. The first $3.00 of the annual

dues of each due paying member shall be set aside for the payment of his subscription to the Journal. Members of affiliated Societies shall be entitled to receive the Journal upon payment of a fee equivalent to the dues charged to an associate member.

SECTION 6. The Council may at its annual joint meeting authorize the printing of special publications to be financed and distributed in a manner approved by the Council.

ARTICLE II. ELECTION OF HONORARY MEMBERS AND FELLOWS

SECTION 1. The Standing Committee on Honors and Awards may submit to the President ninety days before the Annual Meeting the names of any person or persons they deem eligible to election as an Honoray Member or Fellow. Their report shall explain the basis of their recommendation.

SECTION 2. The President shall submit copies of any such reports to all members of the Council not less than sixty days before the Annual Meeting.

SECTION 3. The Council members shall consider all such reports and vote by mail thirty days before the Annual Meeting. Unanimous action by those voting shall be required to elect any person as an Honorary Member or a Fellow.

SECTION 4. In no year may the number of members proposed for election as Fellows exceed two per cent of the number of Active Members, nor may the total number of Fellows ever exceed ten per cent of the number of Active Members.

ARTICLE III. ELECTION OF ACTIVE, ASSOCIATE AND STUDENT MEMBERSHIP

SECTION 1. An applicant for election to Active, Associate or Student Membership shall submit to the Business Manager of the Society an application setting forth in detail his education and experience. The application shall list the names and present addresses of persons who can verify the statements given therein. It shall list not less than three Active Members, Honorary Members, or Fellows of the Society, in good standing who are personally acquainted with the training or experience of the applicant. This application shall be open to inspection at any time.

SECTION 2. The Executive Committee may waive the requirement of references from members of the Society for geographical or other reasons, if the applicant is otherwise eligible and furnishes other satisfactory references.

SECTION 3. The Business Manager shall write to all references for verification of the applicant's statements. The attention of the references shall be specifically called to the Society's Code of Ethics. All replies from references shall be considered confidential and shall not be disclosed except to the Executive Committee, without the references' prior written consent.

SECTION 4. The Business Manager, upon receipt of the replies from all references, shall submit to the Executive Committee the application and the replies from the references.

SECTION 5. Should the Executive Committee unanimously approve and sign the application, the applicant's name shall be published in the next regular issue of the Society's Journal for approval by the membership at large. If no objection to his election is received by the President within thirty days after this publication, he shall be pronounced elected. The Business Manager will notify the applicant.

SECTION 6. An applicant for membership, upon being notified in writing of his election, shall pay full dues for the current year and upon making payment shall receive a membership card and the regular Society publications for the year of entrance. Unless payment of dues is made within thirty days by those living within the continen-

tal United States and within ninety days by those living elsewhere, the Executive Committee may rescind the election of the applicant.

SECTION 7. An Associate or Student Member may seek transfer to Active Membership by supplying added information to show that he has become eligible to election to Active Membership. The transfer shall be handled in the same manner as election to Active Membership. The Standing Committee on Membership may of its own initiative secure the necessary added information and submit it to the Executive Committee.

ARTICLE IV. DUES

SECTION 1. Honorary members shall not be required to pay dues and shall receive the Journal and other publications without charge.

SECTION. 2. The annual dues of an Active Member or Fellow of the Society shall be five dollars ($5.00), which includes the cost of one subscription to the Society's Journal.

SECTION 3. The annual dues of an Associate Member for not to exceed six years after election shall be four dollars ($4.00); thereafter, the annual dues of such Associate Member shall be five dollars ($5.00).

SECTION 4. The annual dues of a Student Member of the Society shall be three dollars ($3.00), which includes the cost of one subscription to the Society's Journal.

SECTION 5. Annual dues shall be payable in advance on January 1 of the calendar year. A bill shall be mailed to each Fellow, Active, Associate or Student Member before that date, stating the amount of annual dues and the penalty for default. The Society's Journal shall be withheld from members pending payment of dues, and Active Members or Fellows failing to pay by ten days prior to the Annual Meeting shall have their votes in the annual mail ballot disqualified. Members in arrears shall lose all privileges of membership until such arrears are met.

ARTICLE V. RESIGNATION OF MEMBERS

SECTION 1. Any member of the Society may resign at any time. Such resignation shall be submitted in writing to the Council.

SECTION. 2. Any member who resigns under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

SECTION 3. Any person who has ceased to be a member under Section 1 of this Article may be re-instated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

ARTICLE VI. EXPULSION OF MEMBERS

SECTION 1. Any member more than two years in arrears shall be dropped from the Society by the Executive Committee.

SECTION 2. Any member who is dropped under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

SECTION 3. Any person who has ceased to be a member under Section 1 of this Article may be re-instated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

SECTION 4. Any member who, after being granted a hearing by the Executive Com-

mittee, shall be found guilty of a violation of the Code of Ethics of this Society or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by unanimous vote of the Executive Committee. The decision of the Executive Committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

Article VII. Election of Officers

Section 1. The Standing Committee on Nominations shall consist of the President, the Past President, and the Prior Past President.

Section 2. The Standing Committee on Nominations shall nominate two or more candidates for each office to be filled. They must secure the consent of all candidates nominated.

Section 3. The Standing Committee on Nominations must submit their ticket to the President in time for publication in the October issue of the Society's Journal.

Section 4. For six weeks after the mailing date of the October issue of the Society's Journal, nominations in writing, signed by at least twenty Honorary Members, Fellows or Active Members in good standing and accompanied by the written consent of the candidate, may be submitted to the President.

Section 5. At the expiration of the aforesaid six weeks period, the Business Manager will prepare and mail to each member, eligible to vote, a ballot listing all candidates properly nominated for each office. The candidates shall be listed alphabetically. With each ballot, the Business Manager shall send an official envelope having the member's name typed on the back.

Section 6. Each member voting shall cast one vote for each officer and shall return his ballot to the Business Manager in the official envelope carrying on the outside the written signature of the member submitting the ballot. Only ballots so prepared by members in good standing, and received by the Business Manager at his officially recognized address not later than ten days prior to the Annual Meeting shall be valid. The Business Manager shall indicate which ballots are valid and shall deliver the ballots unopened to the Standing Committee on Nominations for counting. The Standing Committee on Nominations shall personally supervise the counting of the ballots prior to the Annual Business Meeting. The candidates receiving the greatest number of valid votes cast for an office shall be declared elected to that office. In case of a tie, the Standing Committee on Nominations shall decide by a secret vote which of the candidates shall be elected.

Article VIII. Local Sections

Section 1. Upon petition of twenty members in good standing residing within an appropriate distance of a central point, the Council may authorize the formation of a Local Section and assign a specific territory to the Local Section. The Council may decline to authorize the formation of a Local Section when in its judgment such an organization would not be compatible with the interests of the Society.

Section 2. In the organizing meeting of the Section, all members of the Society residing in the territory assigned by the Council to the Section shall be eligible to vote.

Section 3. The Section shall be known as "The (name of place) Section of the Society of Exploration Geophysicists."

Section 4. The principal work of a Section shall be the holding of regular meetings for the presentation and discussion of papers of interest to its members.

SECTION 5. The Section shall adopt Bylaws which must be approved by the Council of the Society and shall be consistent with the Constitution and Bylaws of the Society.

SECTION 6. The election of District Representatives by the Local Sections shall be by secret ballot. The term of office of a District Representative shall be two years; however, if the Section is entitled to more than one Representative, one of the Representatives elected at the establishment of the Section or added as the result of subsequent growth of the Section, shall be elected for a one year term if this is necessary to prevent the terms of all District Representatives from expiring simultaneously.

SECTION 7. District Representatives shall be elected at least three weeks prior to the Annual Meeting of the Society and shall take office at the close of the Annual Meeting.

SECTION 8. The Secretary of the Local Section shall submit to the Secretary-Treasurer of the Society a report of each meeting of the Local Section or its governing board within two weeks after the meeting. He shall submit to the Secretary-Treasurer of the Society the names of all officers and committee members within two weeks after their election or appointment.

SECTION 9. Any Local Section which for two consecutive years has among its membership fewer than twenty members in good standing of the Society shall automatically be dissolved by the Council at its annual joint meeting. The Council may at any time dissolve any Local Section for reasons it deems good and sufficient.

ARTICLE IX. FINANCES OF LOCAL SECTIONS

SECTION 1. The Society will pay the necessary operating expenses of a Local Section up to the sum of the following amounts: (a) $100.00 per year; (b) $50.00 per meeting up to four meetings per year; (c) $0.50 per member of the Society.

SECTION 2. The Treasurer of the Local Section shall forward, from time to time, his application for such portions of the sum provided in Section 1 as may be needed to the Secretary-Treasurer of the Society, who will arrange for the issuance of a check for the requested amount to the Treasurer of the Local Section.

SECTION 3. Prior to the Annual Meeting, the Treasurer of each Local Section shall transmit to the Secretary-Treasurer of the Society, for approval by the Council, an itemized statement of the expenditure of the funds received from the Society during the preceding calendar year.

SECTION 4. Allocations to a Local Section for the year in which it is established shall be in proportion to the fraction of the calendar year remaining.

SECTION 5. The Local Section may levy dues or raise funds in any other manner, subject to the approval of the Council. Payment of local dues shall, however, not be a prerequisite to participation in any activity financed wholly or in part with funds received from the Society.

ARTICLE X. STANDING COMMITTEES

SECTION 1. The Society shall have the following Standing Committees: (a) Standing Committee on Nominations; (b) Standing Committee on Membership; (c) Standing Committee on Honors and Awards; (d) Standing Committee on Publications; (e) Standing Committee on Program and Arrangements; (f) Standing Committee on Education; and (g) Standing Committee on Student Membership.

SECTION 2. Each Standing Committee shall have a chairman, appointed by the President unless otherwise specified in these Bylaws. The Chairman shall submit a report to the President of the Society at such intervals as the Chairman may deem advisable but at least quarterly. He shall submit to the Council at its annual joint meeting a report covering the activities of the Committee since the previous annual meeting.

SECTION 3. The Standing Committee on Nominations shall consist of the President who shall be chairman, the Past President, and the Past Prior President. Its duties shall be to nominate candidates for officers, to supervise counting the ballots and to declare the election of the officers as prescribed in Article VII of these Bylaws.

SECTION 4. The Standing Committee on Membership shall consist of three active members appointed for a period of one year by the President immediately following the Annual Meeting. One of the members appointed shall have been a member the preceding year. The Committee shall prescribe the manner of soliciting applicants for membership.

SECTION 5. The Standing Committee on Honors and Awards shall consist of five active members, none of whom shall have been members of the Society less than five years. The senior member of the Committee shall retire after the Annual Meeting. Vacancies shall be filled by the President. The Committee shall recommend candidates for election to Honorary Membership or Fellowship to the Council. The Committee shall recommend to the Council the establishment of Honors and Awards and shall recommend candidates for all established Honors and Awards of the Society to the Council.

SECTION 6. The Standing Committee on Publications shall consist of five active members who shall serve a two year term concurrent with the Editor and who shall be appointed by the Editor. The Committee shall have the duty of advising and assisting the Editor. The Editor shall appoint the Chairman of this Committee.

SECTION 7. The Standing Committee on Program and Arrangements shall consist of the Local Representatives plus three to ten additional active members or fellows appointed for a term of one year by the Vice-President, who shall be Chairman. The names of the members of the Committee shall be published in the July issue of the Society's Journal. The Committee shall have the duty of assisting the Vice-President in arranging and holding the Annual Meeting.

SECTION 8. The Standing Committee on Education shall consist of five active members appointed for one year by the President. The Committee shall promote effective geophysical education.

SECTION 9. The Standing Committee on Student Membership shall consist of five active members appointed for one year by the President. The Committee shall encourage the interest of students in geophysics and the Society.

PERSONAL ITEMS

(Members are requested to forward material for inclusion in Personal Items to C. C. Campbell, P. O. Box 1614, Tulsa, Oklahoma)

ORGANIZATION PLANS FOR THE DALLAS SECTION of the Society of Exploration Geophysicists are proceeding under the able direction of A. E. McKay, assistant head of the geophysical section of the Atlantic Refining Company. Over 300 geophysicists and geologists in the Dallas-Fort Worth area were invited to attend the first meeting which was held at 7:30 p.m., October 1, in the auditorium of the Library at Southern Methodist University.

RALPH S. JACKSON, associated with Independent Exploration Company, Houston, Texas since 1932, and Vice-President of that company since 1942, has resigned as of September 15 to enter private practice as a consulting geophysicist. His office will be located in Beeville, Texas.

JAMES B. BATSON has returned to his position as instrument inspector in the Magnolia Oil Company Geophysical Laboratory after four and one-half years of service with the U. S. Army Signal Corps. His address is 3835 Mather Ct., Dallas 11, Texas.

RALPH C. HOLMER, formerly a geological observer for the California Company, is now an instructor in the geophysics department of the Colorado School of Mines. He is working toward a Master's Degree while teaching. His address is Apt. 18, Mines Park, Golden, Colorado.

R. E. MCMILLEN resigned his position as geophyiscal supervisor for Seismograph Service Corporation of Delaware to become geophysical supervisor for Phillips Venezuelan Oil Company. He is located at Caracas, Venezuela, Apartado 1031.

We have been asked to correct the listing for R. H. Dausman in the Membership List published in the April issue of GEOPHYSICS. Mr. Dausman, formerly in the Sales Department of the Harrison Equipment Company, Inc., is now engaged in private practice.—*Bus. Mgr.*

WALTER D. BAIRD, formerly with Geophysical Service, Inc., is now employed by the Southern Geophysical Company in a supervisory capacity. His new address is 308 Sinclair Building, Fort Worth, Texas.

J. FRANK ROLLINS resigned his position as supervisor for Geophysical Service, Inc., on August 15 to become a partner in the Rayflex Exploration Company. His address is now 6923 Snider Plaza, Dallas 5, Texas.

PAUL FARREN, supervisor for National Geophysical Company, was recently transferred from Texarkana to Houston, Texas where he will open a new district office. He may be addressed at 532 Euclid Ave., Houston 9, Texas.

GEORGE N. MEADE, previously employed as a computer by Magnolia Petroleum Company, is now with Stanolind Oil and Gas Company, at P. O. Box 1336, Monahans, Texas.

JAMES E. STONES has been promoted from party chief to seismograph supervisor for The Superior Oil Company. He is located at 2211 Apco Tower, Oklahoma City, Oklahoma.

CLOVIS C. KELLEY, formerly a computer for Independent Exploration Co., is now chief computer for the United Geophysical Company. His new address is Box 97, Sudan, Texas.

ROBERT H. MANSFIELD has taken a new position as seismologist with the Compania Consolidada de Petroleo. He may now be addressed at Apartado 1706, Caracas, Venezuela.

L. B. TROMBLA recently resigned his position as supervisor of seismograph for the Superior Oil Company to help organize the Central Exploration Company, Inc., of which he is now president. His office address is 306 Kerr-McGee Building, Oklahoma City 2, Oklahoma.

A. F. HABER has left the Continental Oil Company to accept a position with the Western Geophysical Company. His address is 2740 Hollister Terrace, Glendale 6, California.

C. G. SCHAUBLE, party chief with Seismograph Service Corp. of Delaware, has been transferred from Colombia to the Venezuelan Division and may be addressed in care of the Company at Apartado 1488, Caracas, Venezuela.

Recently elected officers of the Geotechnical Corporation are W. W. NEWTON, President; J. E. JETT, Vice-President; and T. R. SHUGART, Vice-President.

JOHN L. BIBLE has resigned his position as Executive Vice-President of North American Geophysical Co. and has established offices as a consulting geophysicist specializing in gravity and magnetic supervision and interpretation and residual gravity computations and studies. He has joined with U. E. Neese and Fred A. Lauterbach in organizing Tidelands Exploration Company for performing precise gravity surveys on land and water. U. E. Neese was formerly in the geophysical and geological departments of Stanolind Oil and Gas Co. and recently with North American Geophysical Co. Fred A. Lauterbach was formerly in the geophysical department of Stanolind Oil and Gas Co. and during the past year supervised the gravity operations in the Gulf of Mexico for Robert H. Ray Co. The new offices are located at 2626 Westheimer, Houston 6, Texas.

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In order that this Index to Volume XII may serve as a supplement to the new Cumulative Index covering all publications of the Society from 1931 through 1946 which will be available in the near future, it has been arranged in the same order as that adopted for use in the Cumulative Index. All technical material has been classified first, alphabetically by author; and secondly, by subject in accordance with the following outline:

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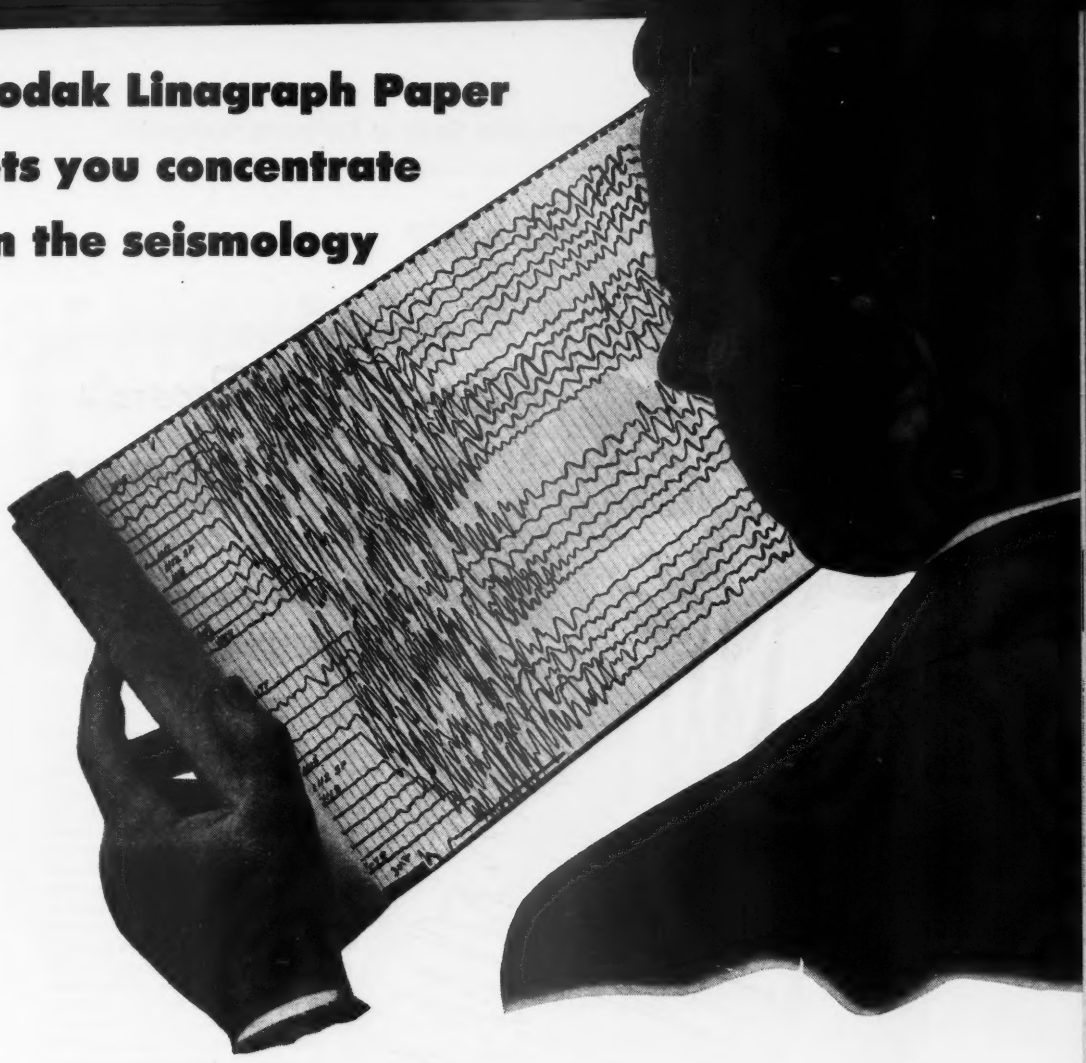

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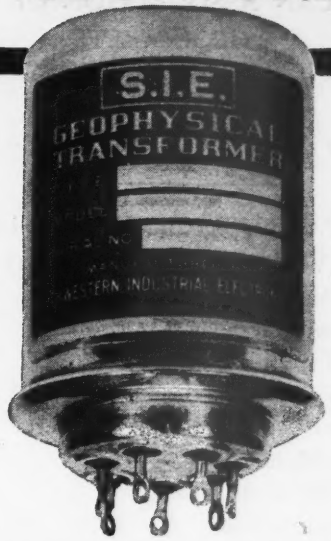

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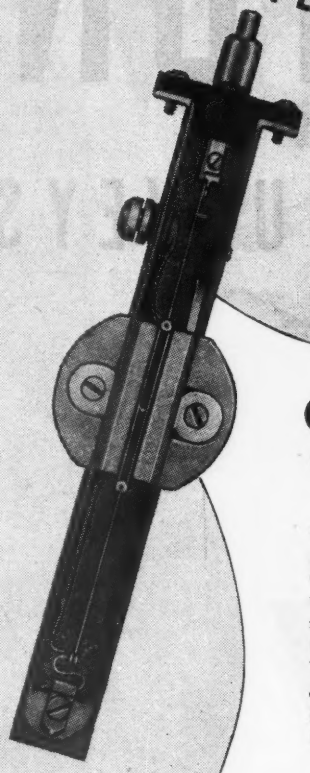

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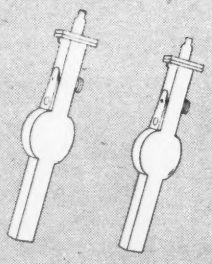

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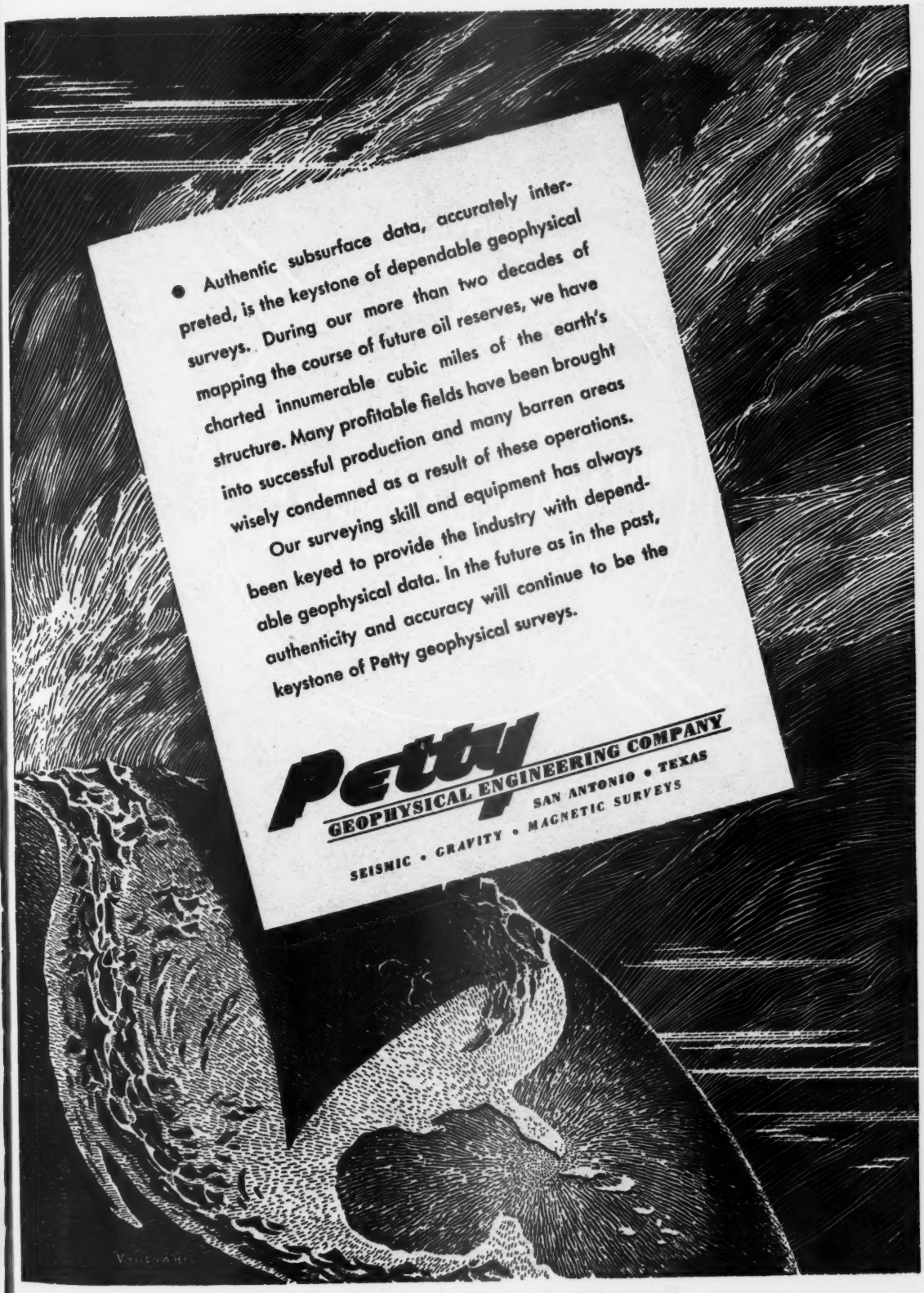
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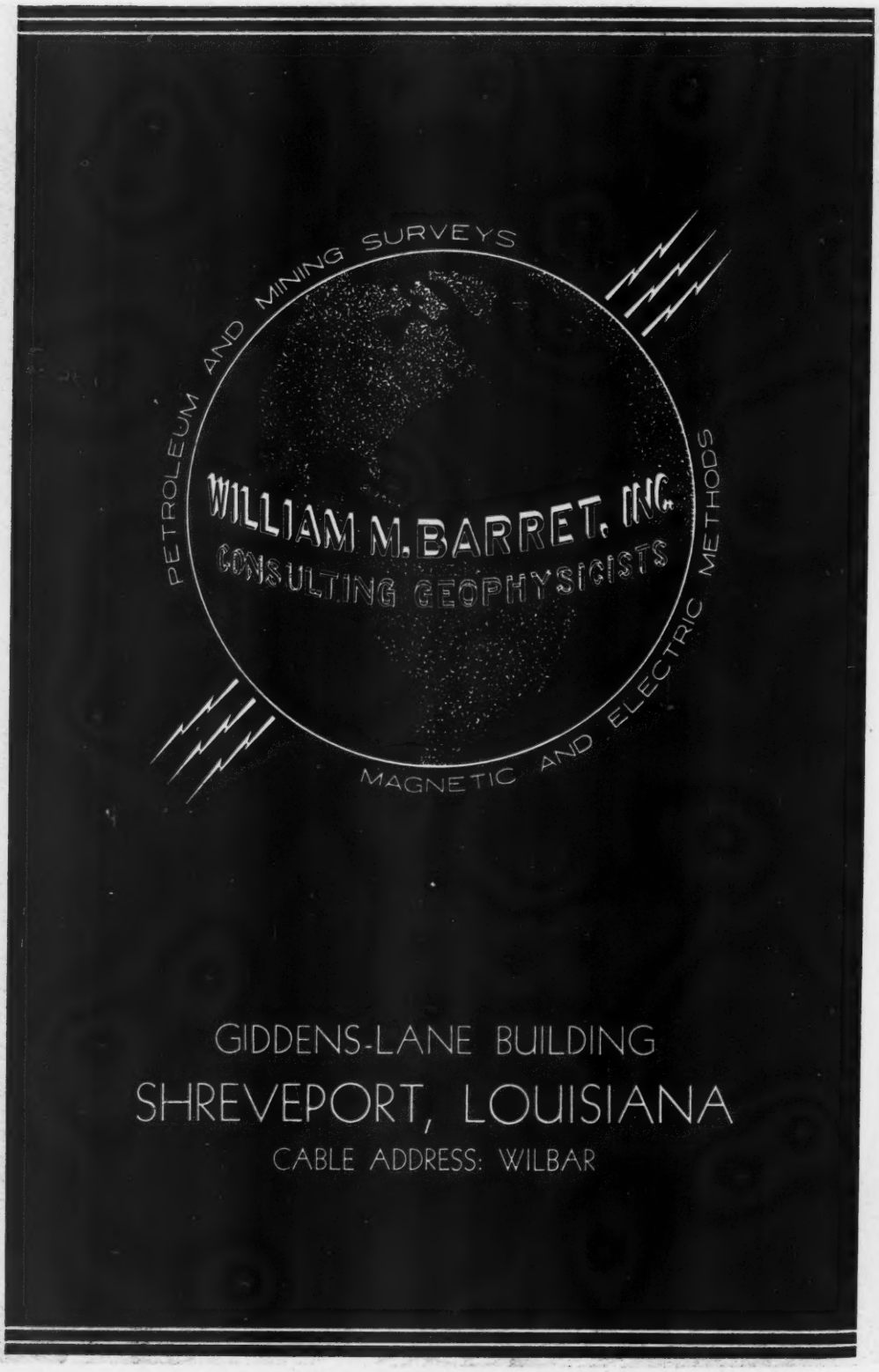
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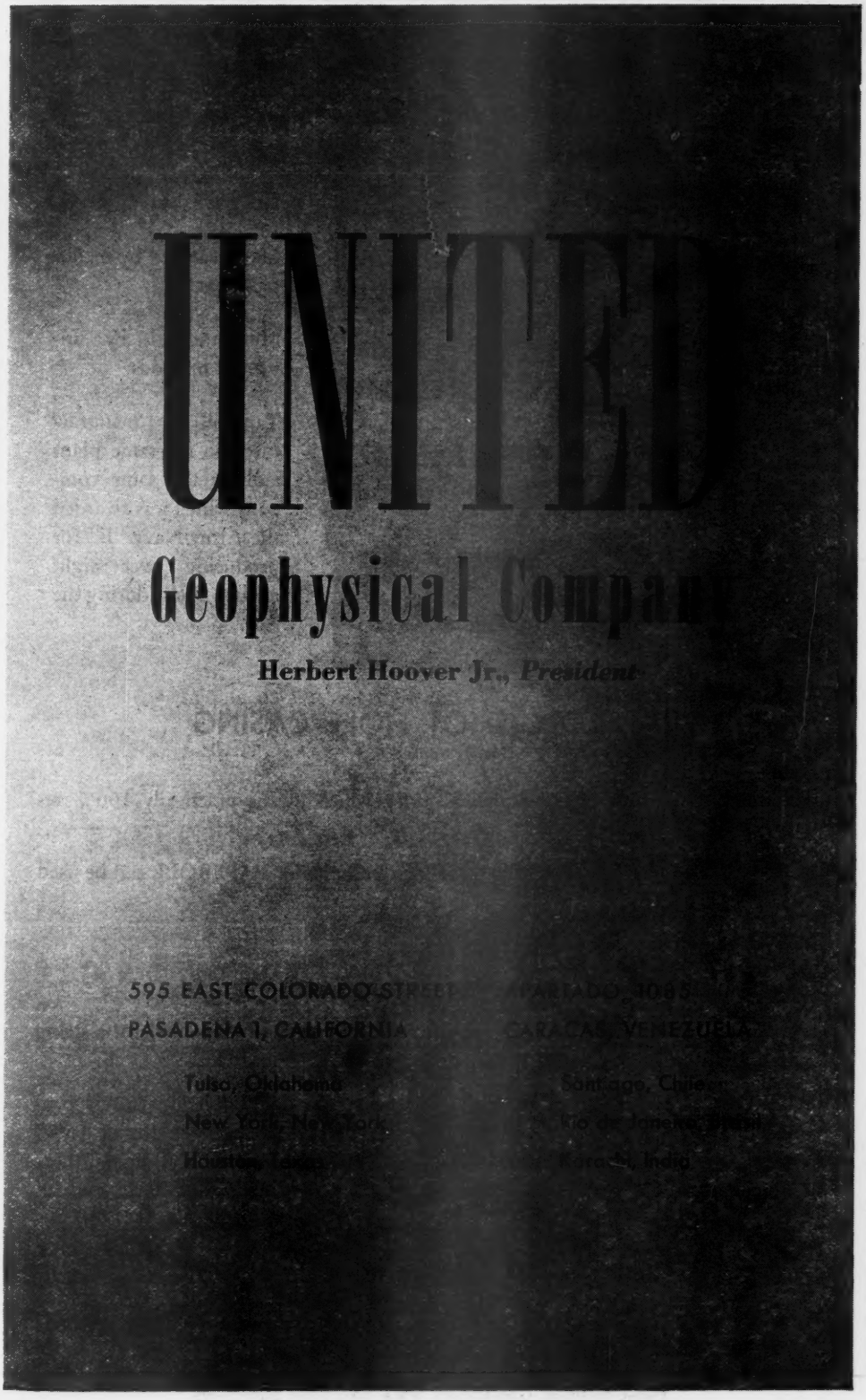
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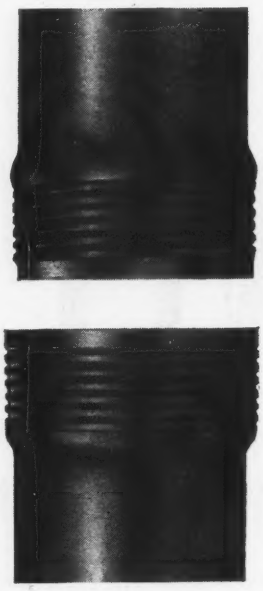

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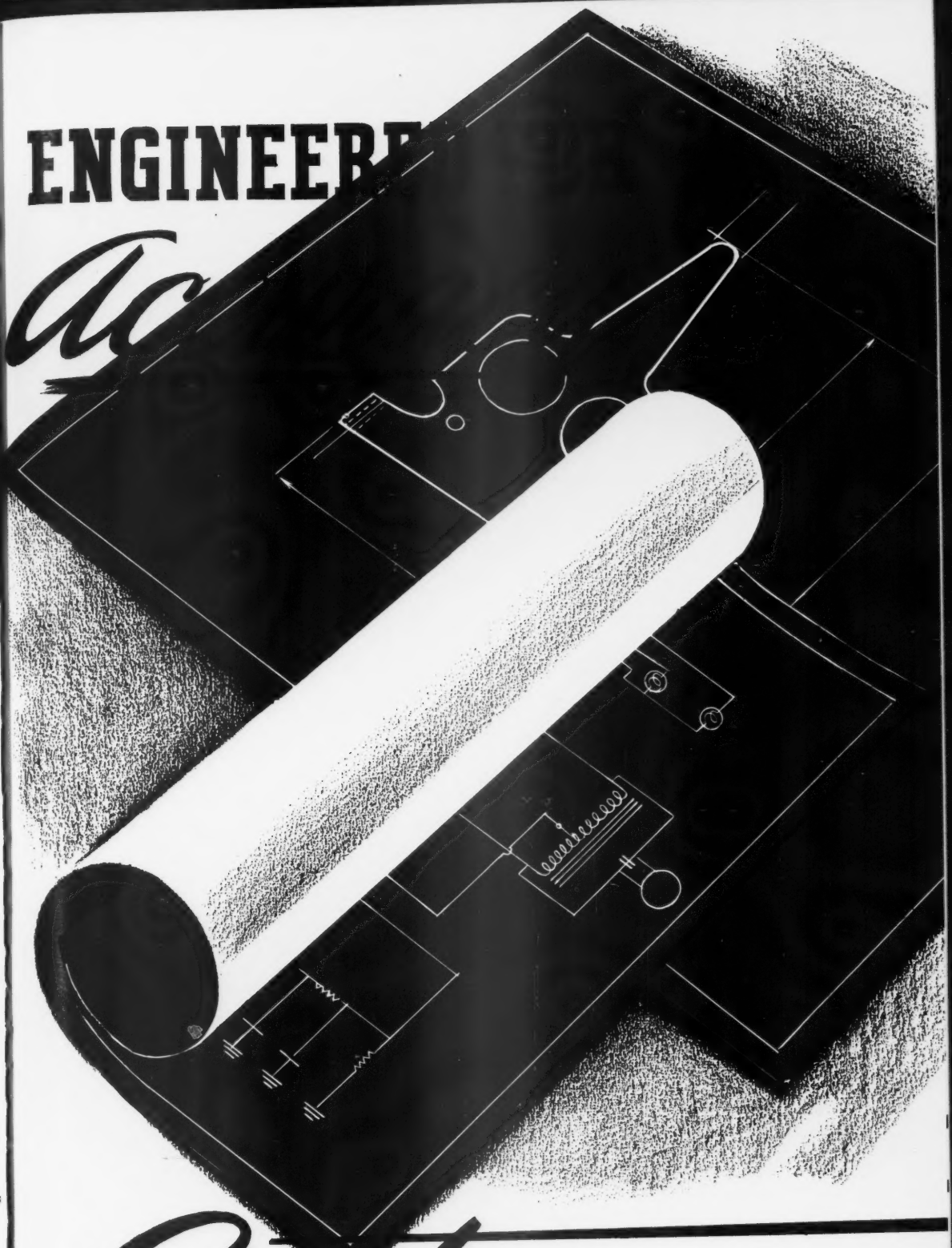

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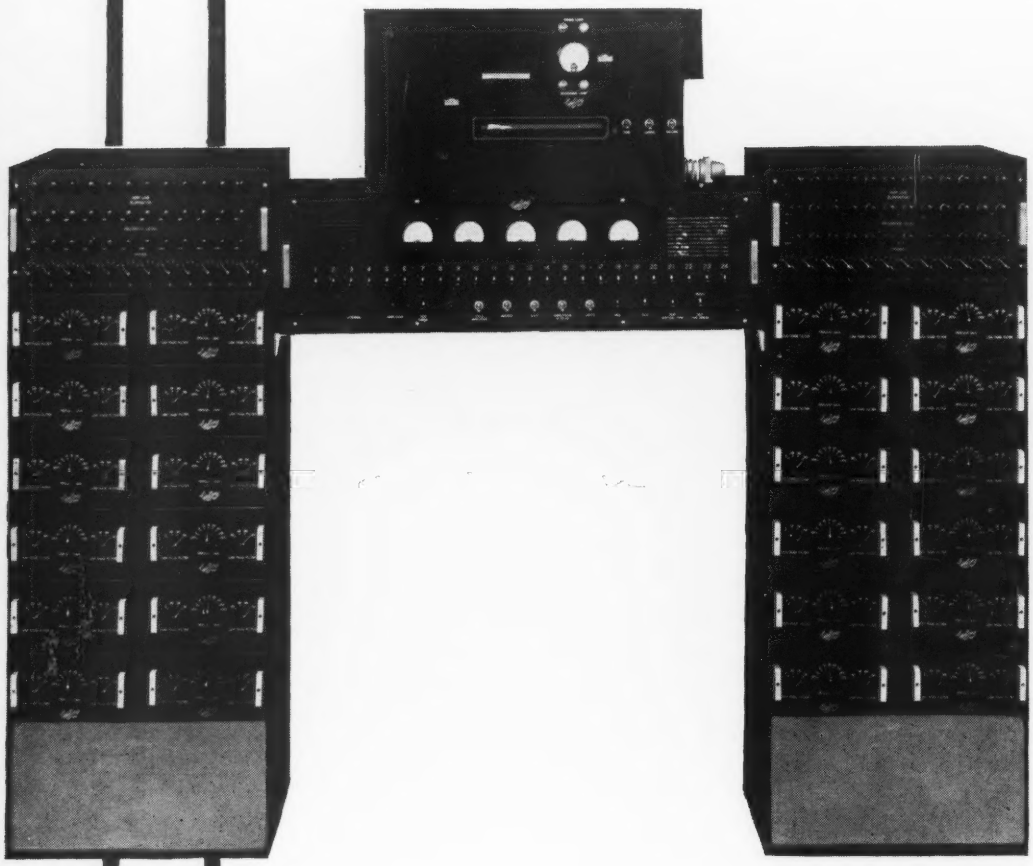

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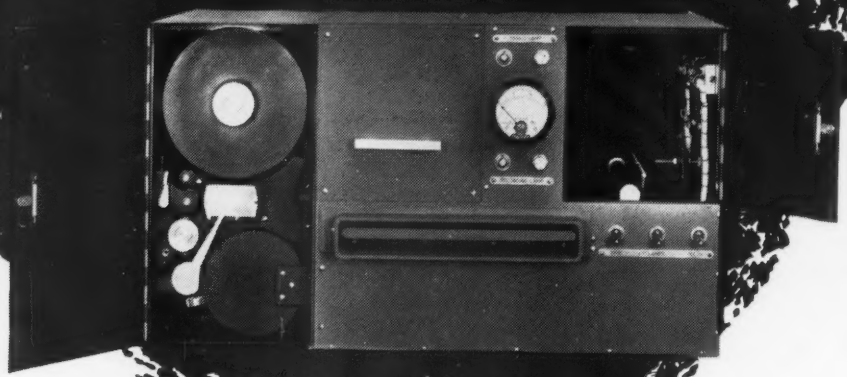

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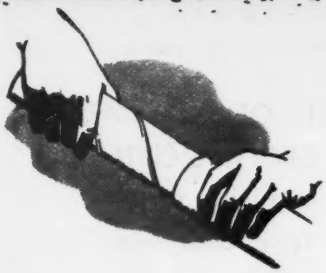

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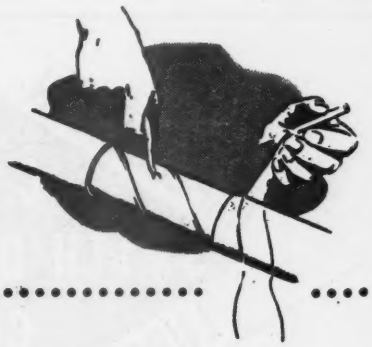

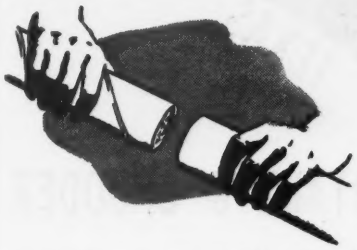

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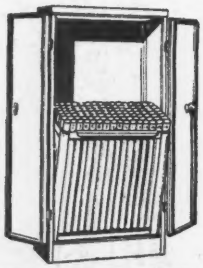

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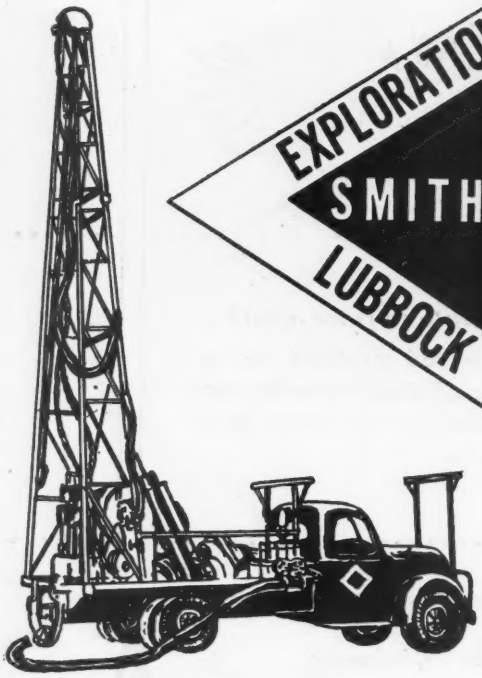

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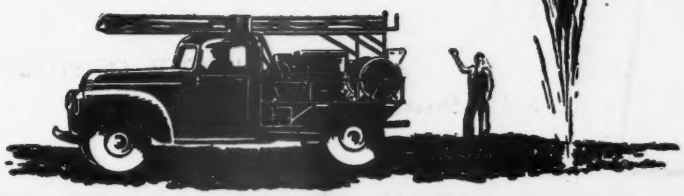

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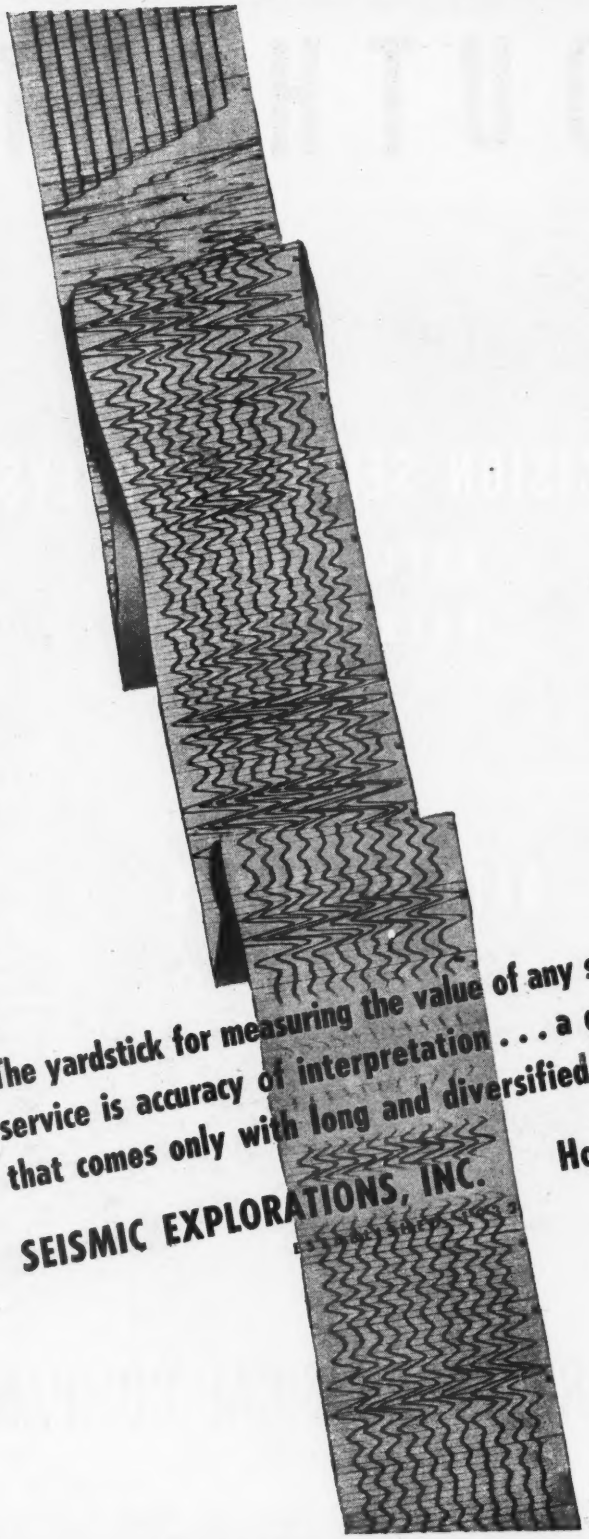
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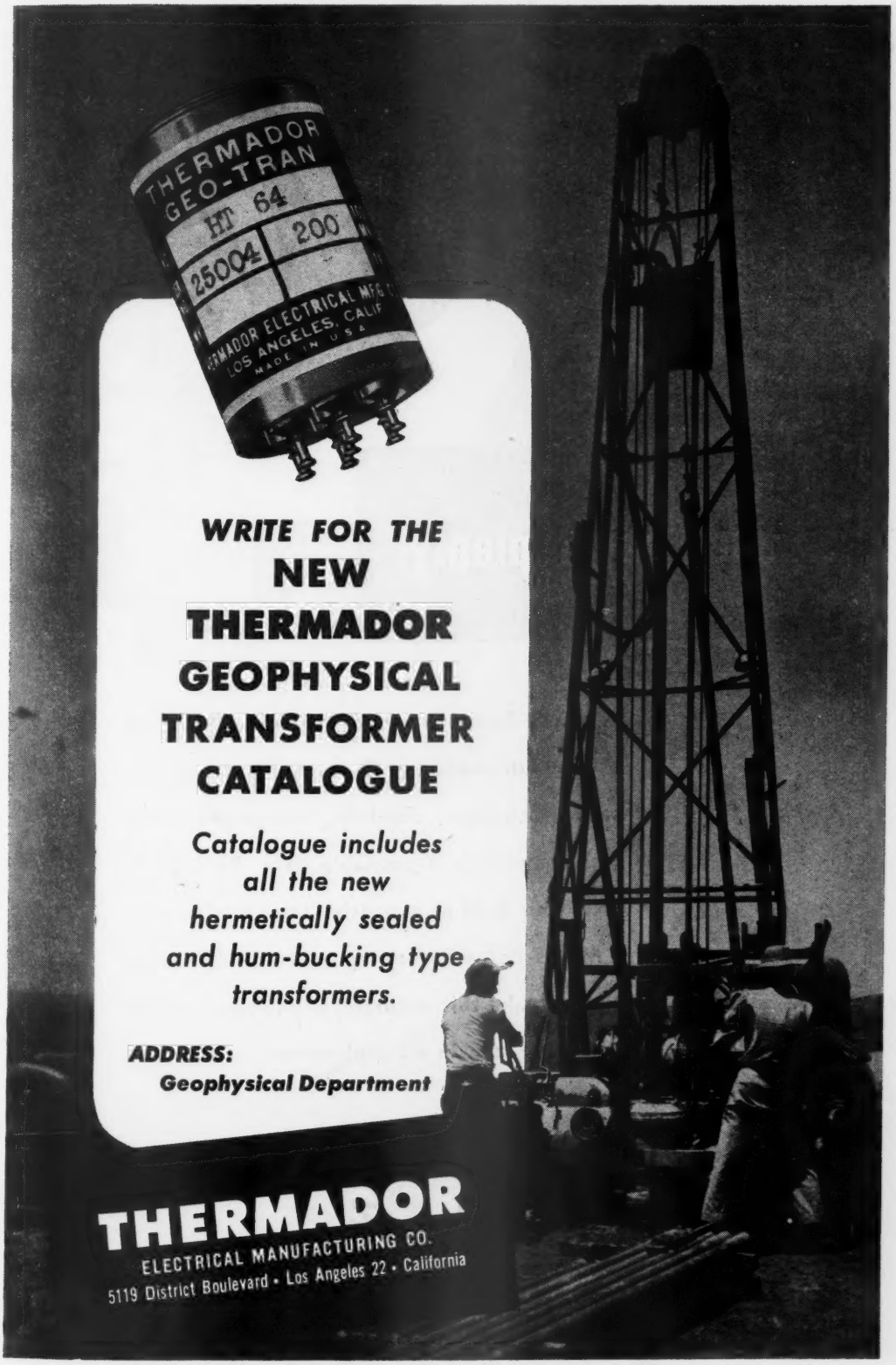
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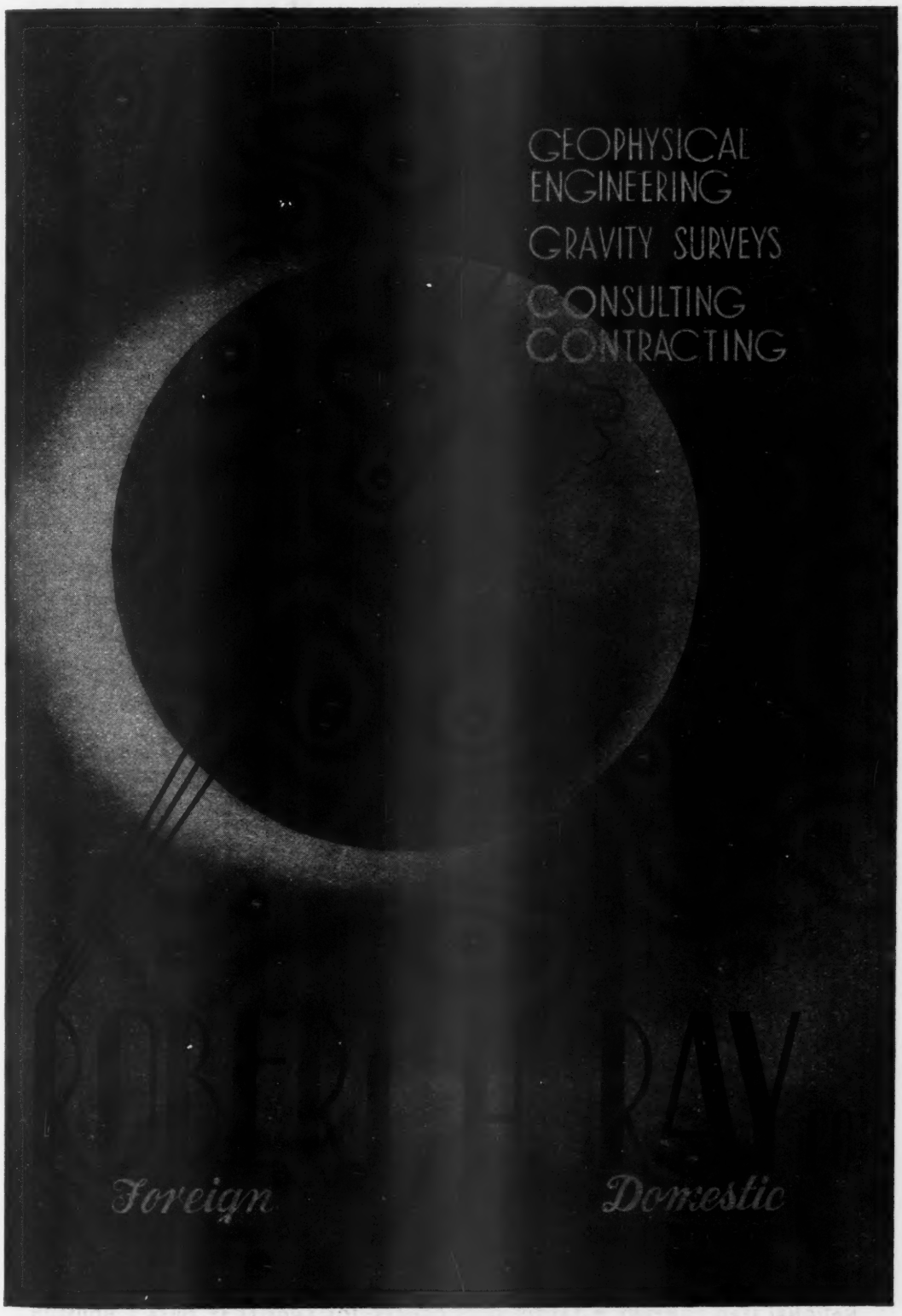
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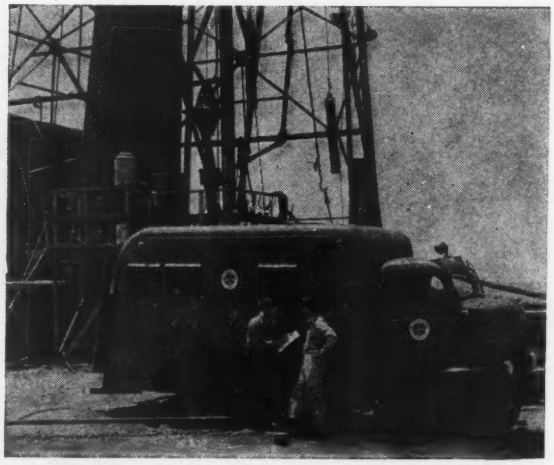

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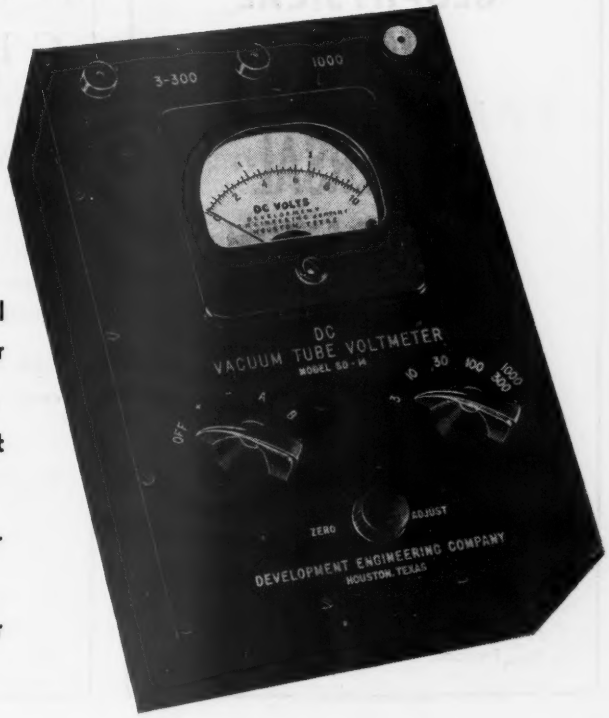

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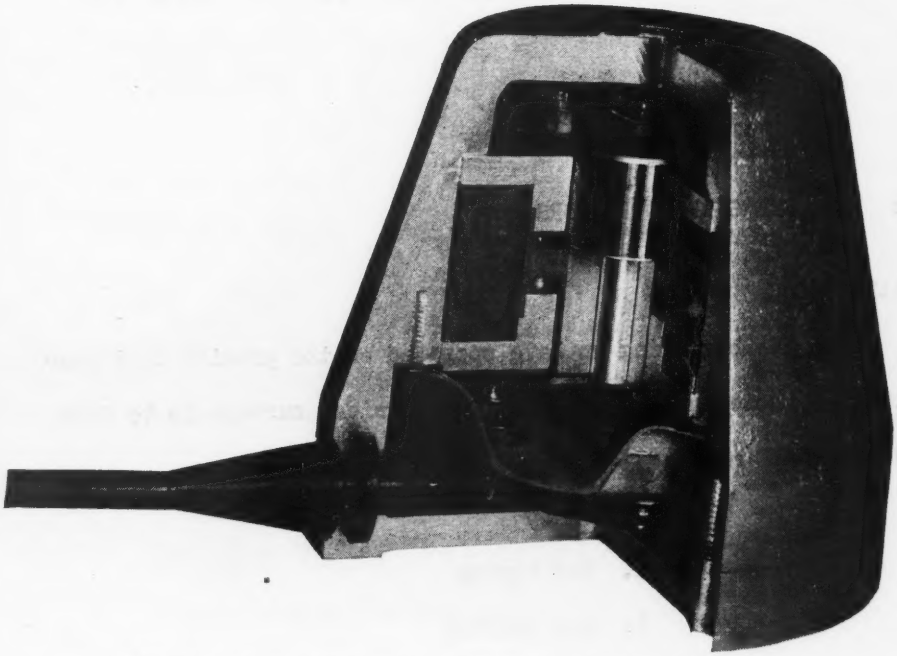

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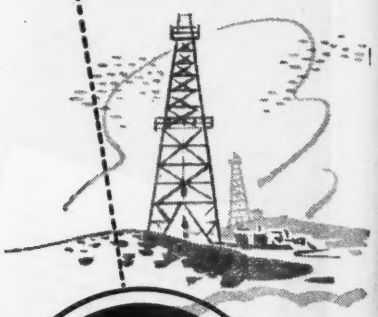

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